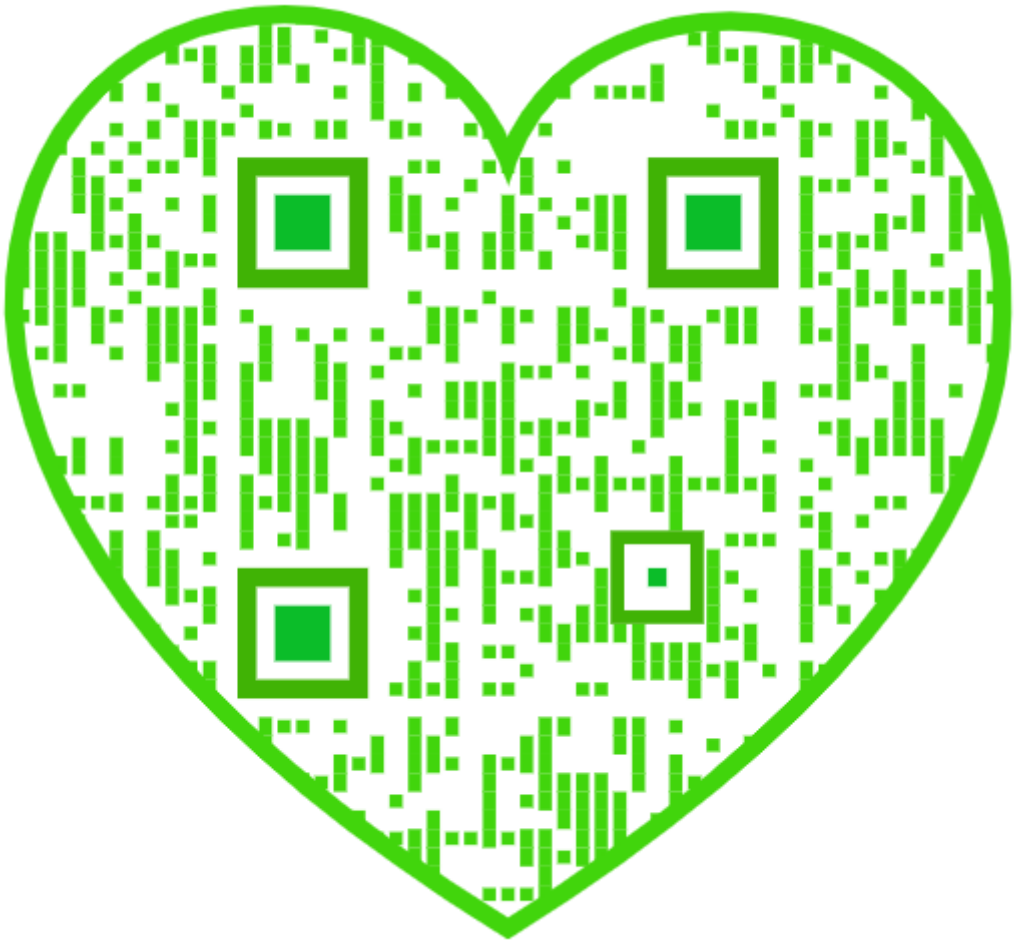

ELECTRIC TRANSMISSION OF POWER.

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ELECTRIC TRANSMISSION OF POWER:

ITS PRESENT POSITION AND ADVANTAGES.

(Richard William Henry)

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PREFACE.

It is needless to dwell upon the benefits of economical transmission of power. Where distance is involved, none of the existing systems are so nearly perfect as to leave no room for fresh trials; on the contrary, all kinds of manufactures and trades are alive to a simple means of transmitting power.

Extensive experience with dynamo-electric machines and their various uses has shown me that electric transmission has before it a very wide field. For this reason, I have collected into the following pages the most reliable data on this subject, and have added some experimental results from my own working. I hope I have furnished to the inquirer that information which will enable him to form his own opinion. It may be well to point out that I do not propose a system of my own nor advocate specially.

First describing the machines employed, their relative merits and demerits, there is next considered the mechanical ratio of the efficiency of this method of transmission, and its applicability either to short or long

distances. Some objections that have been advanced are met, and in conclusion are given some of the most definite advantages of employing electricity.

I hope that the desire to afford information upon a comparatively novel subject may be taken in palliation of shortcomings in style and arrangement.

PAGET HIGGS.

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ELECTRIC TRANSMISSION OF POWER.

CHAPTER I.

DYNAMO-ELECTRIC MACHINES.

WITHOUT the invention of the dynamo-electric machine, transmission of power by electricity could never have become an accomplished fact. But the growth of electrical invention has been so rapid that it may be desirable to indicate what is meant by a dynamo-electric machine, and advisable briefly to review this branch of electricity.

The principles of magneto-electricity were elucidated by Faraday, who found that when a bar of iron is surrounded by a coil or helix of wire and a magnet is approached to or drawn from the bar, a current of electricity is induced in the coil. Further, he found that when one pole of the magnet was approached to the bar, the electrical current had a direction opposite to that electrical current produced when the magnet was receded from the bar: also that the opposite poles of the magnet had opposite actions, or, in other words, produced by the same movement currents of opposite directions. His researches proved that the soft iron and the magnet might change places, and that, generally, electric currents were produced in a coil placed in a magnetic field, either by changes of intensity of this magnetic field, or by the coil being made to cut through magnetic rays of different intensities.

The practical application of this important addition to electrical knowledge soon appeared in the first magneto-electric machine, constructed in 1833, by Pixii. In this machine a horse-shoe magnet was caused to revolve with its poles before those of a double electro-magnet. This machine had the mechanical disadvantage that the heavier part, the permanent magnet, was put in motion. Clarke improved upon this construction in machines of small dimensions, the magnets in which were fixed, and the coil caused to rotate. Machines virtually on the principle of Clarke's machine, but of larger size, were soon constructed by Holmes, of London, and the Compagnie l'Alliance, of Paris. All these machines may be classed as magneto-electric, that is to say, the current produced depends upon the action of magnets upon an electrical circuit.

Magneto-electric machines are quite distinct from electro-magnetic machines, in which the electrical current is made to produce movement, being itself generated by a source foreign to the motor.

Magneto-electric machines are disadvantageous in use, because their effect does not increase with their dimensions, and machines for the production of powerful currents become cumbersome and costly. The rapid rotation, and consequently rapid reversals of magnetism of the iron core, give rise to great heating of the working parts, and to the necessity of cooling these with water. The step from magneto-electric to dynamo-electric machines was due to Mr. S. Alfred Varley, Sir Charles Wheatstone, and Dr. Werner Siemens, who quite independently discovered and worked upon the same principle of accumulation by mutual action, the priority falling to Mr. Varley by his patent. In this construction of machine, induced currents are caused to circulate in the electro-magnet coils that produce them, and are in this way increased. By this mutual action currents are produced, the limit of intensity

of which is co-equal with the maximum limit of magnetic saturation.

This principle of accumulation by mutual action is now employed in all machines where currents of great intensity are required.

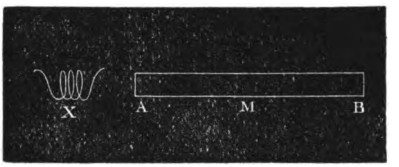
As all these machines can be made to yield electricity, through rotation imparted to them by the expenditure of mechanical power, so can this power be reclaimed, in part, by causing the current generated by one machine to be passed into the coils of a second machine. This second machine will then rotate in an opposite direction, about 50 per cent. of the mechanical power expended upon the pulley of the first machine being obtainable from the pulley of the second. This is the basis of electrical transmission of power.

CHAPTER II.

THE GRAMME MACHINE.

THE machine invented by M. Gramme is essentially the parent of present dynamo-electric machines. To comprehend the principle of the Gramme machine, let Fig. 1

FIG. 1.

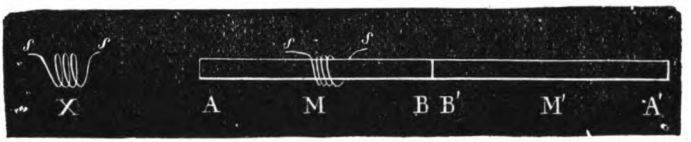


represent a magnetised bar, A B, and a conducting helix, capable of moving to and fro on the bar. If the helix is brought towards the bar from its position at X, an induced current is produced at each movement. These currents are in the same direction while the helix passes the middle, M, of the bar, A B, until it leaves the opposite pole, B. Thus, in the entire course of the helix on to and from the magnet, two distinct periods are to be distinguished: in the first half of the movement the currents are direct, and in the second they are inverted. If, instead of moving from left to right, as we have supposed, the movement is from right to left, everything occurs as before, with the exception that the currents are opposite.

Let two magnets, A B, and B′ A′ (Fig. 2), be placed end to end, in contact by poles of the same name, B B′. The whole forms a single magnet with a consequent point at

the centre. If the helix is moved with relation to this system, it is traversed by a positive current during the first movement, between A and B; by a negative current

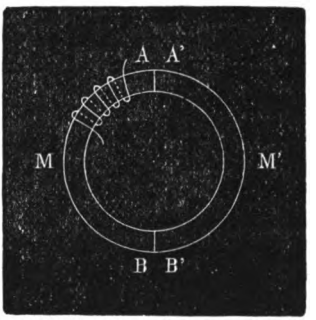
Fig 2.



in the second, from B to B'; again by a negative current in the third, from B' to A'; and finally by a positive current, when leaving A'.

Replacing the straight magnets by two semi-circular magnets (Fig. 3), put end to end, the poles of the same name together, there occur the two poles, A A', B B', and the results are the same as in the preceding, MM' being the two neutral points.

Fig. 3.

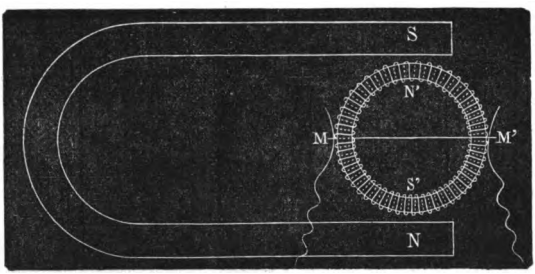


The essential part of the Gramme machine is a soft-iron ring, furnished with an insulated copper helix wound on the whole length of the iron. The extremities of this helix are soldered together, so as to form a continuous wire without issuing or re-entrant end. If the wire is denuded exteriorly, the part bared forms a straight band running round the whole of the circumference Friction-pieces, M and M', are applied to the bared part of the helix. When the ring is placed before the poles, S and N, of a magnet, the soft iron is magnetised

by induction, and there occur in the ring two poles, N′ and S′, opposed to the poles S and N. If the ring revolves between the poles of a permanent magnet, the induced poles developed in the ring always remain in the same relation with regard to the poles N and S, and are subject to displacement in the iron itself with a velocity equal, and of contrary direction, to that of the ring. Whatever may be the rapidity of the movement, the poles N′ S′ remain fixed, and each part of the copper helix successively will pass before them.

An element of this helix will be the *locale* of a current

Fig. 4.



of a certain direction when traversing the path M S M′ (Fig 4), and of a current of inverse direction to the first when passing through the path M′ N M. And, as all the elements of the helix possess the same property, all parts of the helix above the line M M′ will be traversed by currents of the same direction, and all parts beneath the line by a current of inverse direction to the preceding.

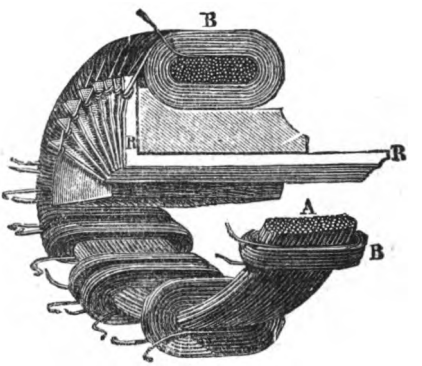
These two currents are evidently equal and opposite, and balance one another. When two voltaic batteries, composed of the same number of elements, are coupled in opposition, it is necessary only to put the extremities of a circuit in communication with the poles common to the

two batteries, and the currents become associated in quantity.

M. Gramme collects the currents developed in the ring of his machine by establishing collectors on the line M M', where the currents in contrary direction encounter each other.

In practice, Gramme does not denude the wire of the ring. Fig. 5 shows the wire and coils. One or two coils

FIG. 5.



(B) are shown in position, and with the iron ring laid bare, and cut.

Insulated radial pieces, R, are each attached to the issuing end of a coil, and to the entrant end of the following coil. The currents are collected on the pieces, R, as they would be on the denuded wire. Their bent parts, brought parallel to the axle, are carried through and beyond the interior of the ring, and are brought near one another upon a cylinder of small diameter. The friction-brushes on the pieces are in a plane perpendicular to the polar line S and N—that is, at the middle or neutral points M and M'. The intensity of the current

increases with the velocity of rotation; the electro-motive force is proportional to the velocity. Gramme modifies his machine so as to produce effects of tension or of

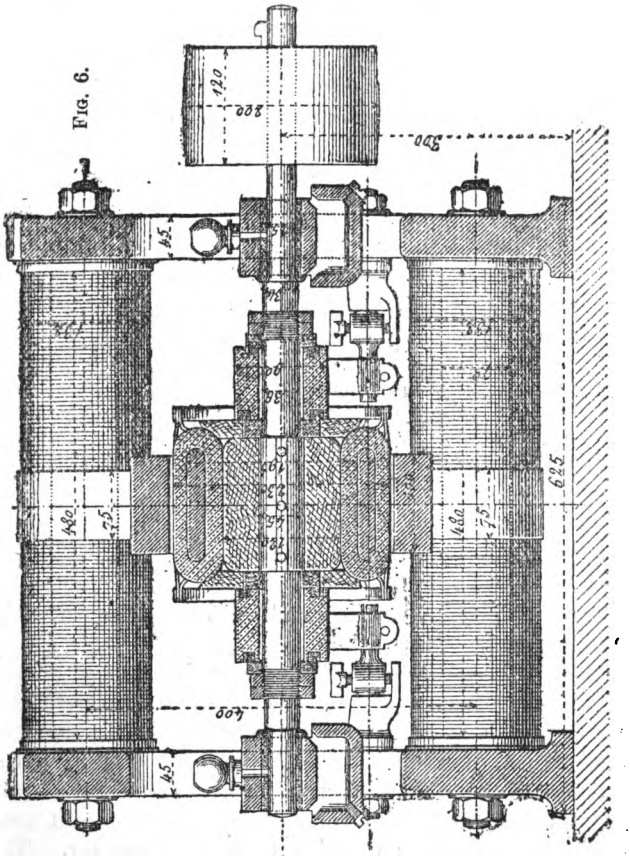
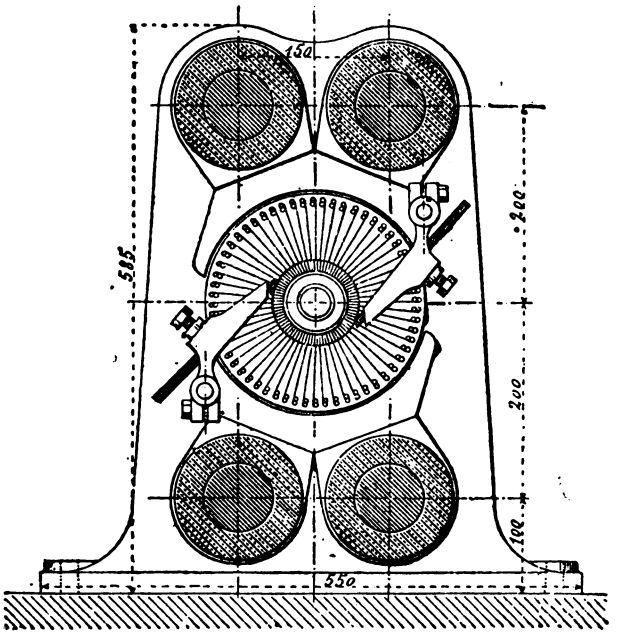


FIG. 6.

quantity, by winding the ring with fine or coarse wire. With equal velocities of the ring the electric tension will be proportional to the number of convolutions of the wire.

Figs. 6 and 7 represent a Gramme machine; it consists of two flanks of cast iron, arranged vertically, and connected by four iron bars, serving as cores to electro-magnets. The axle is of steel; its bearings are relatively very long. The central ring has two wires wound parallel

Fig. 7.



on the soft iron, and connected to two collectors to receive the currents. The poles of the electro-magnet are of large size, and embrace seven-eighths of the total circumference of the central ring. Four brushes collect the currents produced. The electro-magnet is placed in the circuit. The total length of the machine, pulley included,

is 31½ inches, its width 1 foot 9½ inches, and its height 23 inches. Its weight is 880 lbs.

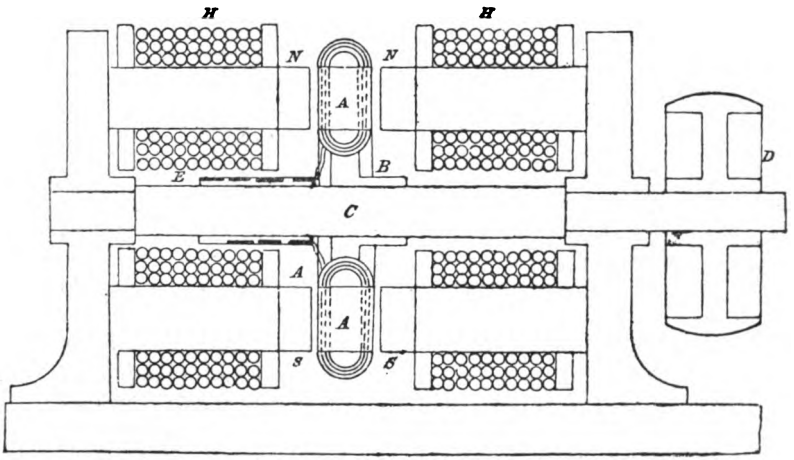
The double coil is connected to 120 conductors, 60 on each side. Its exterior diameter is 27 inches; the weight of wire wound on is 31 lbs. The electro-magnet bars have a diameter of 2½ inches, and a length of 15¾ inches. The total weight of wire wound on the four bars is 211 lbs. The winding of the wires on the ring is effected as if two complete bobbins were put one beside the other, and these two bobbins may be connected in tension or in quantity.

CHAPTER III.

THE BRUSH MACHINE.

MR. BRUSH, the inventor of the machine bearing his name, considers that even the best forms of magneto-electric apparatus are unnecessarily bulky, heavy, and expensive, and are more or less wasteful of mechanical power. The armature of the Brush machine (Figs. 8 to 11) is of

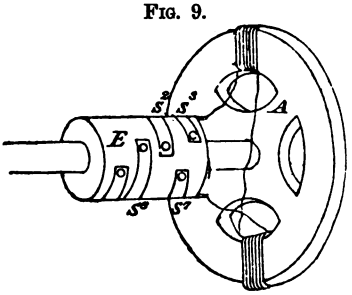
FIG. 8.



iron, in the form of a ring, and is attached to a hub, which is rigidly attached to the shaft C (Fig. 8). The armature, instead of having a uniform cross section, as in the Gramme machine, is provided with grooves, or depressions, in a direction at right angles with its magnetic

axis or length. These grooves are wound full of insulated copper wire, and are of any suitable number. The advantage of winding the wire on the armature depressions is twofold. The projecting portion of the armature between the sections of wire may be made to revolve very close to the poles N N and S S of the magnets, from which the magnetic force is derived, thus utilising the inductive force of the latter to a much greater extent than is possible in the case of annular armatures entirely covered with wire, which therefore cannot be brought very near the magnets. Owing to the exposure of a very considerable portion of the armature to the atmosphere, the heat, which is always developed by the rapidly succeeding magnetisations and demagnetisations of armatures in motion, is rapidly dissipated by radiation and convection. In the case of armatures completely covered with wire, the escape of heat is very slow, so that they must be run at a comparatively low rate of speed, with corresponding effect, in order to prevent injurious heating. Opposite sections on the armature may have their first or their last ends joined together, and their remaining ends connected with two segments of metal of the commutator cylinder E, which is carried by the shaft C, and is of insulating material (Fig. 9).

FIG. 9.



The two metal segments are placed opposite each other on the cylinder, and are each of a length less than half the circumference of the latter, thus exposing the insulating cylinder in two places diametrically opposite each other and alternating with the metal segments. The two segments, say S^3 and S^7, cor-

responding to sections 3 and 7 of wire, hold a position on the cylinder in advance of those of the preceding sections S^2 and S^6 to the same angular extent that the sections 3 and 7 in question are in advance of sections 2 and 6. In this arrangement the number of segments is equal to the number of sections, each segment being connected with but one section. The first and last ends of each section can, however, be attached to two opposite segments, the commutator cylinder, in that case, being constructed with double the number of segments as in the former case, thus making the number of segments double the number of sections. Two metallic plates or brushes, insulated from each other, press lightly upon the cylinder E at opposite points, so selected that while each section of wire on the armature is passing from one neutral point to the other, the corresponding segments on the cylinder will be in contact with them. These plates or brushes collect the currents of electricity generated by the revolution of the armature, one being positive and the other negative. When the section of wire is passing the neutral points on the armature, the plates are in contact with the insulating material of the cylinder between the corresponding segments, thus cutting the section, which is at the time useless, out of the circuit altogether. The necessity for thus insulating each section from the plates during the time it is inactive becomes obvious when it is considered that, if this were not done, the idle section would afford a passage for the current generated in the active sections. During the time a section or bobbin is passing from one neutral point of the armature to the next one, an electric impulse, constant in direction, but varying in electro-motive force, is induced in it. This electro-motive force, starting from nothing at the neutral point, quickly increases to nearly its maximum, and remains almost constant until the section is near the next neutral point,

when it rapidly falls to zero as the neutral point is reached.

The insulating spaces are made of such a length that a section or bobbin is cut out of the circuit, not only when it is at the neutral points, but also during the time when its electro-motive force is rising and falling at the beginning and end of an impulse.

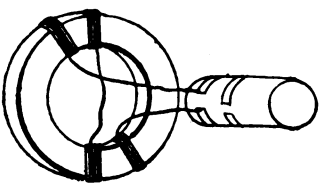
If the insulating space is too short, so as to keep or bring a section in the circuit, while its electro-motive force is low, then the current from the other sections, being of superior electro-motive force, will overcome this weak current and discharge through this section. If the insulating spaces are a little longer than necessary, no material inconvenience results. A suitable length for practical purposes is easily determined experimentally. It is found in practice that the neutral points of the armature in motion are considerably in advance of their theoretical position, this circumstance being attributed to the time required to saturate any point of the armature with magnetism, so that the given point is carried beyond the point of greatest magnetic intensity of the field before receiving its maximum charge. M. Gramme however believes it due to the reaction, by induction, of the armature coils upon the cores and coils of the electro-magnet.

It is necessary to adjust the commutator cylinder on the revolving shaft of the machine with special reference to the neutral points of the armature when in motion, in order that its insulating space may correspond with the neutral points. This adjustment is made experimentally as follows: The commutator cylinder having been placed approximately in its proper position, the machine is started, and the presence or absence of sparks at the points of contact between the plates and commutator cylinder is noted. If sparks occur, the commutator cylinder is turned slightly forward or backward on its axis, until the sparks disappear.

The presence of sparks when the commutator is even slightly out of its proper position is easily explained. If a break between a pair of segments and the plates occurs while the corresponding section of wire on the armature is still active, a spark is produced by the interruption of the current, while if the break occurs too late the section in question will have become neutral, and then commenced to conduct the current from the active sections, and the interruption of this passage causes a spark in this instance. If the commutator is much removed from its proper position in either direction, the sparks are so great as to very rapidly destroy both the commutator and the brushes, while the current from the machine is correspondingly diminished.

With the arrangement, where the first and last ends of each of two opposite sections are attached to two opposite segments the intensity of the induced electrical current will be that due to the length of wire in a single section only, while the quantity will be directly as the number of sections. By doubling the size of each bobbin, and diminishing their number one half, a current of double the intensity and one half the quantity of the former will be obtained. This effect, however, can be secured in another manner, by connecting the first and last ends of the two opposite sections together, and joining the remaining ends only to two opposite segments, as illustrated in Fig. 10. This arrangement is found most convenient in practice.

FIG. 10.



The arrangement of the cylinder E with segments S (Fig. 9) is usually replaced by another, in which the last end of one section and the first end of the succeeding may be connected with a strip of metal

attached to the cylinder, parallel with its axis, as in the Siemens and Gramme machines. These metallic strips or conductors are equal in number to the sections of wire on the armature, and are insulated from each other. The plates press upon the cylinder, in this case, at points corresponding to the neutral points of the armature, thus being at right angles with their position in the first arrangement. This plan, which is the one commonly used with annular armatures, gives fair results, but is subject to a serious disadvantage from which the first is free. The difficulty is, that the sections of wire, when at or near the neutral points of the armature, contribute little or no useful effect, but the current from the other sections must pass through these in order to reach the plates, thus experiencing a considerable and entirely useless resistance; and, owing to the opposite directions of the currents through the active sections on opposite sides of the neutral points, these currents, by passing through the idle sections, tend strongly to produce "consequent" points in the armature where the neutral points should be, thus interfering seriously with the theoretical distribution of the magnetism of the armature. The electro-magnets H are excited by the whole or a portion of the electric current derived from the revolving armature, as is usual in apparatus of this kind, the novel feature of this part of the machine consisting of the manner in which the magnetic poles are presented to the armature; this arrangement is such that a very large proportion of the entire surface of the armature is constantly presented to the poles of the magnets, thus securing uniformity of magnetisation, as well as maximum amount. The iron segments, constituting the poles of the magnets, are arranged on both sides of the armature. The pieces N N, or S S, may be connected at their outer edges, thus forming one piece, and enclosing the armature still more. In the other dynamo-electric machines no magnetic field is maintained when the ex-

ternal circuit is opened, except that due to residual magnetism; hence the electro-motive force developed by the machine in this condition is very feeble. It is only when the external circuit is closed through a resistance

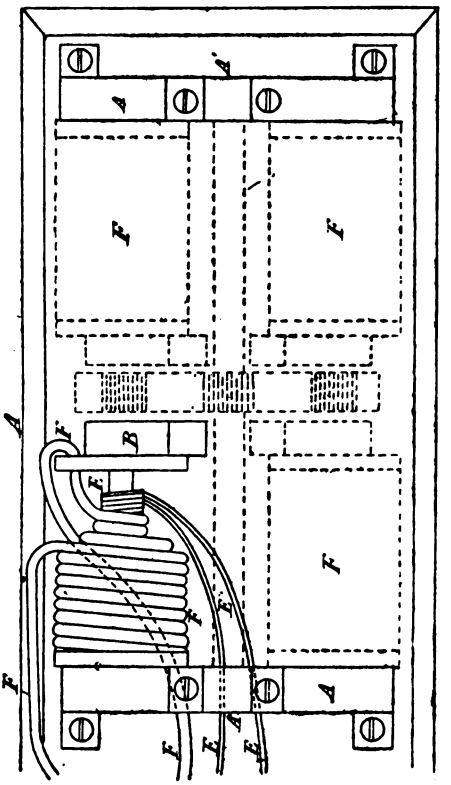


FIG. 11.

not too large that powerful currents are developed, owing to the strong magnetic field produced by the circulation of the currents themselves around the field magnets.

By diverting from external work a portion of the

current of the machine, and using it either alone, or in connection with the rest of the current for working the field magnets, a permanent field may be obtained.

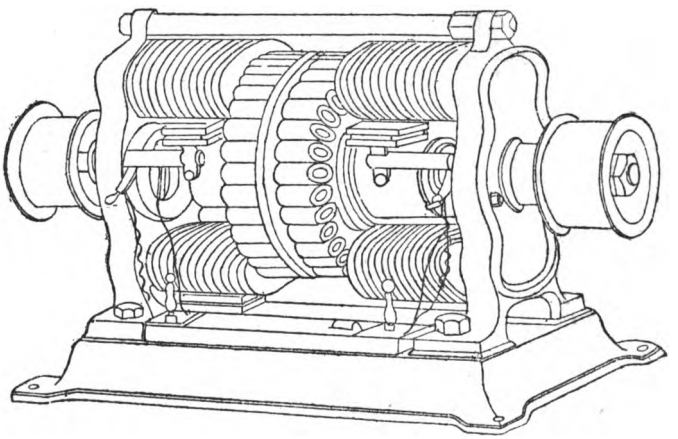
Mr. Brush winds the cores of the field magnets with a quantity of a comparatively fine wire, having a high resistance in comparison with that of the external circuit, and the rest of the wire in the machine. The ends of this wire are so connected with other parts of the machine that when the latter is running, a current of electricity constantly circulates in the wire, whether the external circuit be closed or not. The high resistance of this wire prevents the passage through it of more than a small proportion of the whole current capable of being evolved by the machine; therefore the available external current is not materially lessened. When this device, called a "teaser," is used in connection with field magnets, also wound with coarse wire (Fig. 11), for the purpose of still further increasing the magnetic field by employing the main current for this purpose, then the "teaser" may be so arranged that the current which passes through it will also circulate in the coarse wire, thus increasing efficiency

CHAPTER IV.

THE WALLACE-FARMER AND SIEMENS MACHINES.

In the Wallace-Farmer machine (Fig. 12) the magnetic field is produced by two horse-shoe electro-magnets, but with poles of opposite character facing each other.

Fig. 12.



Between the arms of the magnets, and passing through the uprights supporting them, is the shaft, carrying at its centre the rotating armature. This consists of a disc of cast iron, near the periphery of which, and at right angles to either face, are iron cores, wound with insulated wire, thus constituting a double series of coils. The armature

coils (Figs. 13 and 14) being connected end to end, the loops so formed are connected in the same manner, and to a commutator of the same construction as that of the Gramme. As the armature rotates, the cores pass between the opposed north and south poles of the field magnets, and the current generated depends on the change of

FIG. 13.

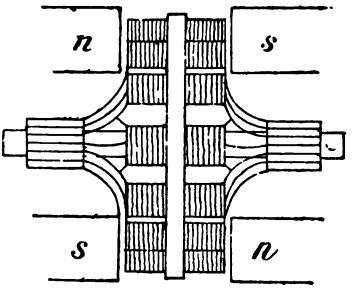
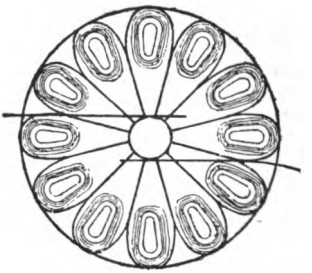


FIG. 14.



polarity of the cores. It will be seen that this constitutes a double machine, each series of coils, with its commutator, being capable of use independently of the other; but in practice the electrical connections are so made that the currents generated in the two series of armature coils pass through the field magnet coils, and are joined in one external circuit.

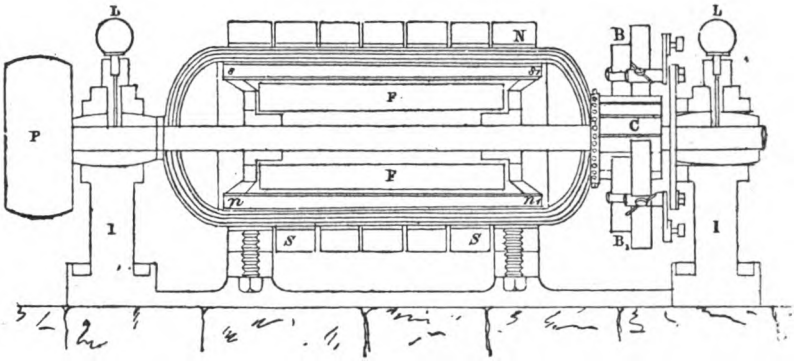
This form of armature also presents considerable uncovered surface of iron to the cooling effect of the air, but, like that of the Brush, presents considerable resistance to rotation.

In the Wallace-Farmer machine there is considerable heating of the armature, the temperature being sometimes sufficiently high to melt sealing-wax.

In the Siemens machine, the conductor of insulated copper wire is coiled in several lengths and convolutions

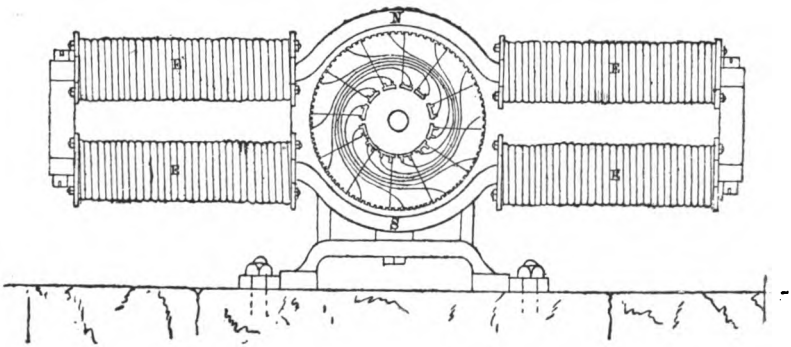
upon a cylinder shown in transverse (Fig. 15), and in end view by Fig. 16. Each convolution is parallel to the

FIG. 15.



longitudinal axis of the cylinder, and the whole surface of the cylinder is covered with wire, laid on in six sections.

FIG. 16.



Surrounding the wire cylinder for about two-thirds of its surface are curved iron bars, the space between these

curved bars and the wire cylinder being as small as is consistent with the free rotation of the cylinder. The curved bars are themselves the prolongations of the cores of large flat electro-magnets; the coils of these electro-magnets and the wire of the cylinder (from brush to brush) forms a continuous electrical circuit. Upon revolution of the wire cylinder, which is supported upon a longitudinal axis in proper bearings, the axis carrying a pulley, a current is generated in it, and this current, initially weak, is directed into the coils of the electro-magnets, magnetising the cores, which induce a still stronger current in the wire cylinder. This mutual action continues until the magnetic limit of the iron is attained. At every revolution of the wire cylinder, the maximum magnetic power acting upon each convolution is attained when the convolution passes through the middle of both magnetic fields, and this power falls to zero when the convolution is perpendicular to that position. Each convolution is therefore subject to a neutral position, and by Lenz's law a convolution starting from that position on the one side of the axis towards the north pole of the electro-magnet would be subject to a direct induced current, and that portion of the convolution on the opposite side of the axis will be traversed by a current of opposite direction, as regards a given point, but of the same direction as regards circuit.

Each of the six sections of wire coiled upon the cylinder consists of two separate coils, the whole having twenty-four ends; two of these ends are brought to each of the segments of a circular commutator in such a manner that the whole six double sections form a continuous circuit, but not one continuous helix.

In order that the segments may be properly presented to the collecting brushes, the connections are arranged according to their relative momentary position. The electric currents are collected upon two wire brushes

tangential to the segments of the commutator, and these brushes form, through the electro-magnets, the two electrodes of the machine; and to the electro-magnet ends are connected the conducting wires leading to the system where the current is to be utilised.

The dimensions, weights, number of revolutions made by the cylinder, and HP. required for driving, are for three sizes of the machine, as under :—

Dimension in Inches.			Weight in lbs.	Revolutions of Cylinder.	HP.
Length.	Width.	Height.			
25	21·0	8·8	298	1,100	1½ to 2
29	26·0	9·5	419	850	3 „ 3½
44	28·3	12·6	1,279	480	9 „ 10

CHAPTER V.

EFFICIENCY OF DYNAMO-ELECTRIC MACHINES.

WHEN two machines are coupled in circuit for the transmission of the power of a prime mover, we may consider two causes of efficiency: (1) that of the first machine as a current generator, and (2) that of the two machines considered together as a transmitting system. In a paper read before the Institution of Mechanical Engineers, by Dr. Hopkinson, it has been pointed out that it is desirable to know what dynamo-electric machines can do with varied and known resistances in the circuit and with varied speeds of rotation; and what amount of power is absorbed in each case.

The mechanical energy communicated by the steam-engine or other motor is not immediately converted into the energy of heat, but is first converted into the energy of an electric current in a conducting circuit. The whole of what is needed to be known may be more easily ascertained and expressed if the subject of inquiry is stated as: what current a machine will produce under various conditions of circuit; and at what expenditure of mechanical power. The subject has been treated more or less by Edlund (Pogg. Annal., 1867 and 1868), Houston and Thomson in America, Mascart ('Journal de Physique,' March 1878), Trowbridge ('Philosophical Magazine,' March 1879), Schwendler ('Report on Electric Light Experiments'). Dr. Hopkinson limits his inquiry to an account of some experiments on the production of currents by a Siemens medium-sized machine, the machine which

is said to produce a light of 6000 candles, by an expenditure of 3½ HP. The intensity of the magnetic field in such machines as the Siemens and ordinary Gramme machines may be regarded as a function of the current passing; to learn what this function is for the machine in question, we may construct a curve in which the abscissæ represent currents passing, and the ordinates the electro-motive force for a given speed of rotation. But the power of a current, that is its energy per second, is the product of the electro-motive force and its intensity; this is in all cases less than the power required to drive the machine, and the ratio between the two may fairly be called the efficiency of the machine. Consider the case of a pump forcing water through a pipe against friction; then electric current corresponds to the water passing per second, and electro-motive force to the difference of pressure on the two sides of the pump; and just as the product of pressure and volume per second is power, so the product of electro-motive force and current is power; which is directly comparable with the power expended in driving the machine or the pump, as the case may be. The peculiarity of the so-called dynamo-electric machine lies in this, that which corresponds to the difference of pressure (the electro-motive force) depends directly on what corresponds to the volume passed (the current). Each experiment requires the determination of the speed, the driving power, the resistances in circuit, and the current passing.

In Dr. Hopkinson's measurements, the speed of the steam engine was maintained very constant by means of a governor specially arranged for great sensitiveness. The speed was varied by means of a weight and a spring, attached to a lever on the throttle-valve spindle. The power was transmitted from the engine to a countershaft by means of a strap, and by a second strap from the countershaft to the pulley of the machine. On this second

strap was the dynamometer (Fig. 17), arranged as used by the Author, and described in a paper read before the Institution of Civil Engineers, 1877–8.

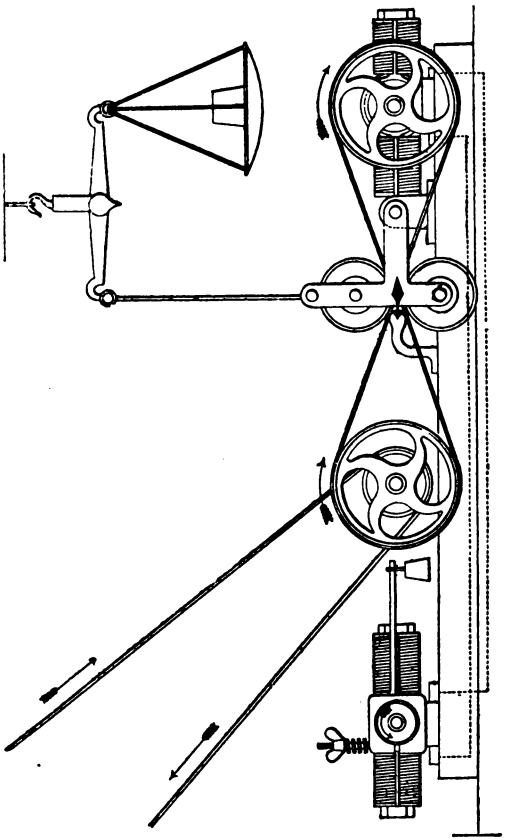


Fig. 17.

The tension difference in the two parts of the strap of the dynamometer and the velocity of rotation of the machine being known, the power received was

obtained, expressed in gram-centimètres per second. Multiplying by 981, the value of gravity in centimètres and seconds, the power is then expressed in ergs * per second, and is ready for comparison with the results of the electrical experiments.

The dynamo-electric machine in these trials was a Siemens medium size; the armature coil has fifty-six divisions, and the brushes are single, not divided—that is, each brush is in connection with one segment of the commutator at each instant. The leading wire was 100 yards of seven copper wires, insulated with tape and india-rubber, and having a diameter of about 9·6 millimètres. The current passing was ascertained by the heating of the calorimeter, or by measuring the difference of potential at the extremities of a resistance, all the resistances of the circuit being known. The resistance coils comprised ten coils of common brass wire, each, wound round a couple of wooden uprights driven into a baseboard common to the set; each wire was about 60 mètres long, and of No. 17 Birmingham wire-gauge, weighing about 14·6 grammes per mètre. Each terminal was connected to a cup of mercury excavated in the baseboard, so that the coils could be placed in series or in parallel circuit at pleasure. The resistance of each coil being about 3 ohms, this set could be arranged to give resistances varying from 0·3 to 30 ohms.

The calorimeter was a double copper vessel; a resistance coil of uncovered German-silver wire nearly 2 mètres long, 1·5 millimètres in diameter, and having a resistance of about $\frac{1}{5}$ ohm, was suspended within it from an ebonite cover,

* The dyne is the force which will in one second impart to one gramme a velocity of one centimètre per second, and an erg is the work done by a dyne working through a centimètre; a horse-power may be taken as three-quarters of an ergten per second, an ergten being 10^{10} ergs. See Report of Brit. Assoc. 1873, and Everett, 'On the Centimètre-Gramme Second System of Units.'

which also carried a little brass stirrer; and the calorimeter was filled with water to the level determined by the mark of a scriber. It was, of course, necessary to know the capacity of the calorimeter for heat. It was filled with warm water up to the mark, and the coil placed in position; 120 grammes of water were then withdrawn, and the temperature of the calorimeter was observed to be 58·8° centigrade; after the lapse of one minute it was 58·3° centigrade; after a second minute, 57·9° centigrade. 120 grammes of cold water, temperature 13·3° centigrade, were then suddenly introduced through a hole in the ebonite cover, and it was found that two minutes after the reading of 57·9° centigrade, the temperature was 50·0° centigrade; hence it was inferred that the capacity of the calorimeter is equal to that of 750 grammes of water. The resistance coils were on the binary scale, from $\frac{1}{8}$ ohm to 1024 ohms. The battery was a single element of Daniell's battery, in which the sulphate of zinc solution floats on the sulphate of copper; its electromotive force is assumed to be $\frac{8}{8}$ volt. The resistances added in the battery circuit are pencil lines on glass, such as are described in the 'Philosophical Magazine,' February, 1879. Preliminary to experiments on the current, determinations of resistances were made. When the ends of the cable were connected, the resistance was found to be 0·129 ohm. The resistances in the machine were found to be as follows, when cold: magnet coils, 0·156 and 0·152 respectively; armature coil, 0·324; total, 0·632. Direct examination was made of the whole machine in eight positions of the commutator, giving 0·643 ohm, with a maximum variation from the mean of 0·6 per cent. After running the machine for some time, the resistance was found to be 0·683, an increase which would be accounted for by a rise of temperature of 12° centigrade, or thereabouts. The resistance of the calorimeter is 0·20, without its leading wire, which may be

taken as 0·01. There were thus three leading resistances which must be considered: (1), the resistance of the machine and leading wire, assumed throughout as 0·81, denoted by c_1; (2), the resistance of the brass coils, C, calculated from the several determinations, with the addition of the resistance of the leading wire, 0·02, and denoted by c_2; (3), when present, the resistance of the calorimeter and leading wire denoted by c_3.

Two approximate corrections were employed, and should be detailed. The first is the correction for the considerable heating of the resistance coils *c*. These were arranged in two sets of five each, five being in parallel circuit, and two sets in series. The current from the machine, being about 7·4 webers in each wire, was passed for three or four minutes; the circuit was then broken, and the resistance c_2 was determined within one second of breaking circuit, when it was found to be about 5 per cent. greater than when cold. As the resistance was falling, the following was adopted as a rule of correction: square the current in a single wire, and increase the resistance c_2 by $\frac{1}{10}$ per cent. for every unit in the square. The second correction is due to the fact that the calorimeter was losing heat all the time it was being used. It was assumed that it loses 0·01° centigrade per minute for every 1° centigrade, by which the temperature of the calorimeter exceeds that of the air; this correction is, of course, based on the experiment already mentioned.

The method of calculation may now be explained:

R is the total resistance of the circuit, equal to $c_1 + c_2 + c_3$;

Q is the current passing in webers;

E the electro-motive force round the circuit in volts;

W_1 the work per second converted into heat in the circuit, as determined by the galvanometer, measured in ergtens per second;

W_2 is the work per second as determined by the calorimeter;

W_3 is the work per second as determined by the dynamometer, less the power required to drive the machine when the circuit is open.

H P is the equivalent of W_3 in HP.; n is the number of revolutions per minute of the armature. Then:

$$Q = 981 \times \frac{a+b}{b} \times \frac{1}{c_2},$$

$$E = Q\,R$$

$$W_1 = E\,Q$$

also $W_2 = \frac{R}{0{\cdot}2}$ multiplied by the mechanical equivalent of the heat generated per second in the calorimeter.

The accompanying tables give the results of the experiments. A power of 0·21 ergtens, or 0·28 HP., was required to drive the machine at 720 revolutions on open circuit. An examination of the table shows that the efficiency of the machine is about 90 per cent. exclusive of friction. Comparing experiments 11 and 13, and also the last four experiments, it is seen that the electro-motive force is proportional to the speed of rotation within the errors of observation. Experiments 14, 15, and 16 were intended to ascertain the effect of displacing the commutator brushes.

The principal object of the experiments was to ascertain how the electro-motive force depended on the current. This relation is represented by a curve (Fig. 18) in which the abscissæ represent the currents flowing, or the values of Q in the table, and the ordinates the electro-motive forces, or the values of E reduced to a speed of 720 revolutions per minute. The curve may also be taken to represent the intensity of the magnetic field. There will be a point of inflection in the curve near the origin. The experiments 1 to 5 indicate that this is the true form of the curve, and it is confirmed in a remarkable manner by a

special experiment. A resistance intermediate between $5\frac{1}{3}$ and 4 was used in circuit, and E and Q were determined in two different ways; first, by starting with an open circuit, which was then closed; secondly, by starting with a portion of the resistance short circuited, and a very powerful current passing, and then breaking the short circuit. It was found that E and Q were four times as great in the latter case as in the former. The curve (Fig. 18) will also determine what current will flow at any given speed of rotation of the machine, and under any conditions of the circuit, whether of resistance or of opposed electro-motive forces. It will also give very approximate indications of the corresponding curve for other machines of the same configuration, but in which the number of times the wire passes round the electro-magnet or the armature is different.

It will be well to compare these results with those obtained by others. M. Mascart worked on a Gramme machine with comparatively low currents; he represents his results approximately by the formula,

$$E = n(a + b\,Q),$$

where a and b are constants. This corresponds to the rapidly-rising part of the above curve. Mr. Trowbridge with a Siemens machine obtained a maximum efficiency of 76 per cent., and states that the machine was running below its normal velocity. Mr. Schwendler's *précis* states that the loss of power with a Siemens machine in producing currents of over 20 webers is 12 per cent. Now, taking Dr. Hopkinson's experiments, 4 to 19, the mean value of W_1 is 3·027, and of W_3 3·304; adding to the latter 0·21, the power required to drive the machine when no current passes, it appears that 13·8 per cent. of the power applied is wasted. Again, taking experiments 4, 6, 8, 10, and 12, the mean value of W_2 is 2·888 and of W_3, 3·076, indicating a waste of power amounting to

12 per cent. Of the loss, 0·28 HP. is accounted for by friction of the journals and commutator brush; the remainder

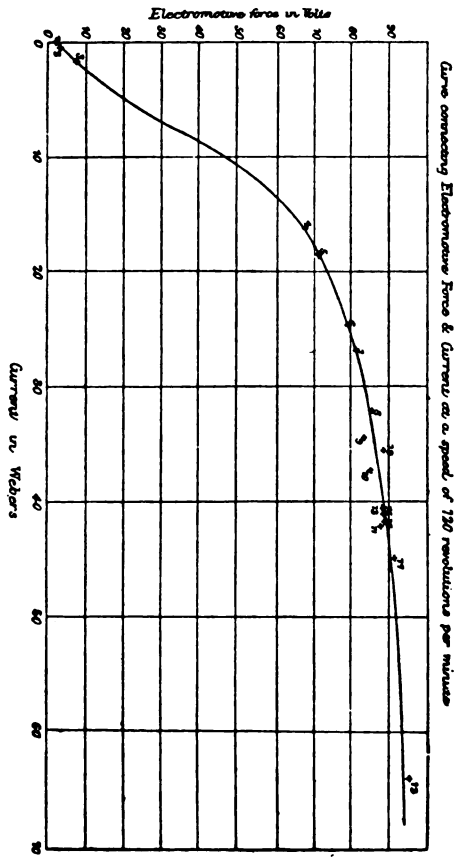

Electromotive force in Volts
Current in Webers
Curve connecting Electromotive Force & Current at a speed of 120 revolutions per minute

Fig. 18.

is expended in local currents, or by loss of kinetic energy of current when sparks occur at the commutator.

Number of Experiment.	Total Resistance R.	Current Webers Q.	Electromotive Force in Volts E.	W_1.	W_2.	W_3.	HP.	n.	Position of Commutator Brush.
1	1,025·0	0·0072	2·72	..	..	..	..	720	Original position as supplied from maker.
2	8·3	0·48	3·95	0·0019	..	..	..	,,	
3	5·33	1·45	7·73	0·0112	..	0·042	0·056	,,	
4	4·07	16·8	68·4	1·149	1·140	1·179	1·59	,,	
5	3·88	18·2	70·6	1·285	..	1·263	1·68	,,	
6	3·205	24·8	79·5	1·972	2·158	2·106	2·81	,,	
7	3·025	26·8	81·1	2·147	..	2·392	3·19	,,	
8	2·62	32·2	84·4	2·718	2·888	2·780	3·71	,,	
9	2·43	34·5	83·8	2·894	..	3·370	4·49	,,	
10	2·28	37·1	84·6	3·138	2·903	3·538	4·72	,,	
11	2·08	42·0	87·4	3·671	..	3·960	5·28	,,	
12	1·345	64·0	86·1	5·510	5·349	5·777	7·70	654	(Strap slipping.)
13	2·08	41·1	85·5	3·514	..	3·790	5·05	698	
14	2·07	36·0	74·5	2·682	..	2·852	3·80	696	13° extra lead of brush.
15	2·09	42·7	89·2	3·809	..	4·233	5·64	708	8° less lead of brush than in original position.
16	2·09	41·7	87·2	3·636	..	4·135	5·51	713	5°
17	2·10	45·0	94·5	4·252	..	4·810	6·41	759	5°
18	2·08	40·8	84·9	3·464	..	4·010	5·35	696	5°
19	2·06	35·1	72·3	2·538	..	2·672	3·56	586	5°

CHAPTER VI.

PRACTICABILITY OF TRANSMISSION OF POWER BY ELECTRICITY.

To deal with objections first, we may regard the transmission of large electric currents as considered by Mr. J. T. Sprague, who examines the suggestions of Mr. Siemens. In a lecture delivered at Glasgow, March 14, 1878, and since published, Mr. Siemens says, "The principal objection that has been raised by electricians to the conveyance of power to the distance of miles, is on account of the apparently rapid increase in the size of the conductor required with increase of distance. In order that the magneto-electric machine may work under the most favourable conditions, it should have an internal resistance depending in a great measure upon the nature of the work to be performed, but not exceeding for quantative effects 1 ohm or unit of resistance. If the resistance is greater, a notable proportion of the power expended will be converted into heat in the conductors, causing both loss of effect and great inconvenience. By another law the electrical resistance of the circuit exterior to the machine should be somewhat, but not much, larger than the internal resistance, say 1·5 unit. The external resistance is composed of two elements, namely, the conductor, and the resistance of the electric lamp or electro-magnetic engine, which latter may be taken also as amounting to 1 unit, leaving only half a unit available for the conductor. These conditions determine really the size of the conductor for any distance to which the current has to be conveyed.

"Suppose the distance to be half a mile, a copper wire of ·23-inch diameter will produce the half-unit resistance,

which is already a wire of considerable dimensions, for the purpose of working a single lamp. If the distance be doubled wire of the same thickness will give twice the electrical resistance, and in order to reduce it again to half a unit its sectional area must be doubled, so that a conductor of 30 miles' length would require to be 60^2 = 3,600 times the weight of the half-mile conductor, and this enormous increase in weight would certainly be required if the object to be accomplished was the working of one electric lamp by a dynamo-electric machine. My critics have, however, fallen into the error of overlooking the fact that half-a-unit resistance is the same for a circuit capable of working one lamp as it is for working 100 or 1000 lamps.

"Electricity is not conducted upon the conditions appertaining to a pipe conveying a ponderable fluid, the resistance of which increases with the square of the velocity of flow; it is, on the contrary, a matter of indifference what amount of energy is transmitted through an electric conductor; the only limit is imposed by the fact that in transmitting electric energy, the conductor itself retains a certain amount proportional to that transmitted, which makes its appearance therein in the form of heat."

This heat, as Mr. Siemens goes on to explain, would increase the resistance of the conductor; but to simplify the problem that heat and its effects are not taken into account in the following remarks, Mr. Sprague assumes that the heat is radiated away or got rid of, so as to keep the conductor at a uniform temperature. According to Mr. Sprague, there are two ways of regarding "resistance":—

1. In Ohm's formulæ it is constant for all currents. So is the diameter of a pipe transmitting water. The same pipe will deliver any variable quantity or current of water corresponding to the pressure; so the same wire

will deliver any variable quantity or current of electricity corresponding to the electro-motive force. This aspect of resistance then is a mathematical one, existing only in calculations.

2. True, or practical resistance, is measurable by the energy required to overcome it. The energy expended by a current in passing a given conductor (resistance in the mathematical sense being simply the reciprocal of the conducting power under unit condition) varies as the square of the current or velocity of flow.

Therefore, electricity is really conducted under precisely the "conditions appertaining to a pipe conveying a ponderable fluid."

The resistances in a circuit are of several orders:—

1. That of the actual conductor itself, which is constant.

2. Any work effected by the current. This may in some cases be expressed as a counter electro-motive force, in others simply as a resistance, but in either case it can be represented in ohms, or as a reduced length; but the expression of it is variable, because it depends upon the energy expended from moment to moment, and it must be expressed by the square root of that energy involved in Ohm's formulæ.

When all forms of energy expended are thus expressed as resistance in ohms, the ratio of useful work done, to the inevitable expenditure in developing and transmitting the energy to the work, is exactly proportional to the resistance of each part of the circuit.

There is a difficulty, continues Mr. Sprague, in applying these principles to the illustrations employed by Mr. Siemens, in that we do not know what is meant by the resistance of 1 ohm at the point of work done. If by that is meant simply the wire resistance of an electro-motor or of a lamp, these belong to the side of energy lost or expended; if the work to be done is not included in the 1 ohm, then it would seem that, as it would act as an

additional resistance, the internal resistance of the generating machine must be increased in order to develop the requisite electro-motive force.

For the present purpose, then, which is to indicate the nature of the problem and the difficulties to be met, rather than how to overcome them, Mr. Siemens' actual figures may be taken, and the 1 ohm be assumed as the relative *useful* ratio of the lamp or motor engine. Here we meet at once the problem, what is the work done in, or the mechanical equivalent of an electric light of, say, 1000 candles?* Does any one know? The problem involves these simultaneous measures—illuminating power, resistance, and current. With batteries of known electro-motive force this can replace the latter data required. We have all sorts of statements, from 5 to 1 ohm for resistance, to the figures given by Messrs. Ayrton and Perry, which come out as follows :—

Grooves in Series E. M. F. 1·8.	Total E. M. F. Volts.	Resistance.			Current Webers.	Energy in Arc, Foot-lbs.
		Battery.	Arc.	Total.		
60	108·0	12·0	12·0	24·0	5·33	15,082
80	144·0	16·0	20·0	36·0	4·00	14,157
122	219·6	24·4	30·0	54·4	4·04	21,647

Unfortunately there is no measure of the light produced in these three cases. Taking the common statement that such a light consumes 1 HP. of an engine (though Mr. Siemens states that his smaller size converts 2 HP., and gives 1250 candles) and take the resistance as 1 ohm in the arc and 1·5 in the machine and conductor; this

* As far as regards the conductor, it is immaterial whether the current conveyed is utilised to produce light or motor-power. Hence the words of the argument have been retained.

gives $33{,}000 \div \frac{1}{2 \cdot 5} = 13{,}200$ feet pounds expended in the arc, a very singular approximation (considering by how different a road it has been reached) to the figures above. The mechanical equivalent of the weber-ohm current per second is ·787 foot pound, or 44·24 per minute.

$\frac{13{,}200}{44 \cdot 24} = 289 \cdot 37$, the square root of which, 17·273, represents the current developing 13,200 foot pounds per minute in the ohm resistance, a useful effect of 0·4 of the power expended.

If, now, 100 such lights were to be applied to the same circuit conditions, it would be necessary to put in circuit ten in series, and ten such series in multiple arc to maintain their total joint resistance = 1, and the current would have to be $17{,}273 \times 10 = 172 \cdot 73$, developing 100 times as much heat in machine and conductor, and still expending 0·6 of the power in transmission. This also supposes that there is perfect insulation, and no loss on the road, a condition of things not likely to be attained in practice. In converting the current again into mechanical power, the 0·4 of power sent would be reduced by the effective ratio of the transforming machine.

In regard to Mr. Siemens' proposal to convey 1000 HP. a distance of 30 miles through a conductor 3 inches in diameter, he says, "The electrical resistance of the conductor would be 0·18 unit, and supposing that the total resistance in circuit was made 2·5 units, which, as I before stated, gives a favourable working condition, it follows that $\frac{0 \cdot 18}{2 \cdot 5} \times 1000 = 72$ HP. would be expended in heating the conductor. This would represent about 15 lbs. of coal per hour, a quantity quite insufficient to raise a mass of 1900 tons of copper, with a surface of 132,000 square feet to a sensibly-heated condition."

It seems from this, the proposal is not to convey 1000 HP. but only so much as is possible out of that original power. Then, giving machine 1 and conductor 0·18 ohm resistance, we have 1·32 left for useful work; so we divide it:—

1	Dynamo machine	400 HP.
0·18	Conductor	72 „
1·32	Engine or lights	528 „

This latter figure being reduced in actual work to probably 300 at most.

To obtain the 300 HP., then, we have to provide:—

1. Machines for converting the electricity into 300 HP.
2. 1900 tons of best copper rod carefully insulated.
3. Machines capable of converting 1000 HP. into electricity.
4. Appliances and processes for getting rid of 400 HP. worth of heat in this latter machinery.

Mr. Siemens says he is convinced that the sectional area of the conductor might safely be reduced to 2 inches, giving half the weight of the conductor; but as the converting engines would probably cost as much as gas engines of equal power, the question resolves itself into this, is it better worth while to lay down even 950 tons of copper, and fit up the 1000 H.P. engines, or to purchase the fuel needed to work the 300 H.P. engines where they are to be used? That is a question that might receive different answers in the mountains of Chili, and where coal is to be obtained at even the most extreme English prices.

Mr. Sprague's views are practically answered by the able paper presented to the Franklin Institute by Professors Thomson and Houston; the statements made as to the size and cost of the cable that would be needed to convey the power of Niagara Falls to a distance of several hundred miles by electricity, having induced with

the Authors the hope that they may throw light upon this interesting subject.

As an example of some of the statements alluded to, the following are cited, viz.:—That made by a certain electrician, who asserts that the thickness of the cable required to convey the current that could be produced by the power of Niagara, would require more copper than exists in the enormous deposits in the region of Lake Superior. Another statement estimates the cost of the cable at about £12 per lineal foot.

As a matter of fact, however, the thickness of the cable required to convey such power is of no particular moment, and the Professors state that it is possible, should it be deemed desirable, to convey the total power of Niagara *a distance of* 500 *miles or more by a copper cable not exceeding one-half of an inch in thickness.* This, however, is an extreme case, and the exigencies of practical working would not require such restrictions as to size. The following considerations will elucidate this matter:—Suppose two machines connected by a cable of, say, 1 mile in length. One of these machines, for example A, is producing current by the expenditure of power; the other machine, B, used as an electrical motor, is producing power by the current transmitted to it from A by the cable C. The other terminals, x and y, are either put to earth or connected by a separate conductor.

Let us suppose that the electro-motive force of the current which flows is unity, since, by the revolution of B, a counter electro-motive force is produced to that of A, the electro-motive force of the current that flows is manifestly the difference of the two. Let the resistance of A and B together be equal to unity, and that of the mile of cable and connections between them the 0·01 of this unit. Then the current which flows will be $C = \frac{E}{R} = \frac{1}{1 \cdot 01}$. If, now, an additional machine A′ and an additional motor

B′, and an additional mile of cable be introduced into the above circuit, the electro-motive force will be doubled, and the resistances will be doubled, the current strength remaining the same as $C = \frac{E}{R} = \frac{1+1}{1{\cdot}01+1{\cdot}01} = \frac{2}{2{\cdot}02}$. Here it will be seen that the introduction of the two additional machines A′ B′ has permitted the length of the cable, C, to be doubled without increasing the strength of the current which flows, and yet allowing the expenditure of double the power at A A′, and a double recovery at B B′ of power, *or, in other words, a double transmission of power without increase of current.*

Increase now the number of machines at A to, say, one thousand, and one of those at B in like proportion, and the distance between them, or the length of the cable, one thousand times, or in the case we have supposed make it one thousand miles, its diameter remaining the same, then, although the same current will flow, yet, *we have a thousand times the expenditure of power at one end of the cable and a thousand-fold recovery at the other end, without increase of current.* And the same will be true for any other proportion.

Since the electro-motive force is increased in proportion to the increase of power transmission, the insulation of the cable and machines would require to be proportionally increased.

As an example it may be mentioned that a dynamo-electric machine used for A may have a resistance of, say, 40 ohms and produce an electro-motive force of, say, 400 volts. Such a machine might require from three to five horse-power when used in connection with a suitable motor B, for recovery of the power transmitted.

If the resistance of the motor B be, say, 60 ohms, and the cable transmitting the currents a distance of 1 mile be 1 ohm, then the current $C = \frac{400}{60+40+1} = \frac{400}{101}$.

If, now, 1000 machines and 1000 motors and 1000 miles of cable, each of the same relative resistances, be used the current $C = \frac{1000 \times 400}{1000 \times 101}$, which has manifestly the same value as before. If the supposition of the power used to drive one machine be correct, then from 3000 to 5000 HP. would be expended in driving the machines, and possibly about 50 per cent. of this amount recovered. Then we have from 1500 to 2000 HP. conveyed a distance of 1000 miles. What diameter of copper cable will be required for such transmission? Since this cable is supposed to have the resistance of 1 ohm to the mile, calculation would place the requisite thickness at about $\frac{1}{4}$ inch. If, however, the distance be only 500 miles, then the resistance per mile may be doubled, or the section of the cable be decreased one half, or its diameter will be less than one-fifth of an inch.

For the consumption of 1,000,000 HP. a cable of about 3 inches in diameter would suffice under the same conditions. However, by producing a much higher electromotive force, the section of the cable could be proportionally reduced until the theoretical estimates given in the preceding lines might be fulfilled. The enormous electro-motive force required in the above calculation would, however, necessitate such perfect insulation of the cable that the practical limits might soon be reached. The amount of power required to be conveyed in any one direction would, of course, be dependent upon the uses that could be found for it, and it is hardly conceivable that any one locality could advantageously use the enormous supposed power we have referred to.

Stripped of its theoretical considerations, the important fact still remains, that with a cable of very limited size an enormous quantity of power may be transferred to considerable distances. The burning of coal in the mines, and the consequence of the power generated by the flow

of rivers, may therefore be regarded as practicable, always, however, remembering that a loss of about 50 per cent. will be almost unavoidable.

In a subsequent series of experiments, details of which are unpublished, the Professors Thomson and Houston have succeeded in transmitting considerable power through a wire only 0·004 inch in diameter. Sir William Thomson has made statements that are in general accordance with these views. Mr. Siemens has remarked that the electrical transmission of power, although new and untried, is one of considerable interest, and an amount of from 40 to 50 per cent. is recovered at the end of the line. By putting one machine to work with an expenditure of, say, 3 HP., a power could be produced and utilised at a distance not exceeding half a mile or a mile, according to the size and length of the conductor, equal to nearly one-half that amount. If at certain stations 100 HP. were so exerted, it would be possible to distribute over a town power which would be exceedingly convenient and free from the dangers and troubles attending caloric motors, and with an expenditure of fuel certainly not greater, because, although perhaps only 40 per. cent. of the power exerted at the central station was actually obtained at the further station, it was nevertheless obtained at a very low rate. A 100-HP. engine, economically constructed, would produce 1 HP. with less than 3 lbs. of coal, whereas a small motor of 2 or 3 HP. would consume probably 6 to 8 lbs. of coal per hour. Bearing that difference in mind, the magneto-electric machine would be an economical one. How far the principle would be applicable ultimately for the utilisation of such natural forces as water-power from a distance, remains to be seen. The difficulty is in regard to the length of the electrical conductor. Its resistance increased in the ratio of its length; and as the increased resistance would mean loss of useful effect in the same proportion, it would be necessary to double the area of

the electric conductor in doubling its length, in order to maintain the same ratio of efficiency; but, if that were done, the resistance might be increased to many miles, and, he believed, profitably, without further loss of power.

Professors Houston and Thomson have, however, shown as noted in the preceding lines how this loss is to be avoided.

In order to get the best effect out of a dynamo-electric machine, there should be an external resistance not exceeding the resistance of the wire in the machine. Hitherto, Mr. Siemens continues, it has been found not economical to increase the resistance in the machine to more than 1 ohm, otherwise there was a loss of current through the heating of the coil. If, therefore, there was a machine with 1 ohm resistance, there ought to be a conductor transmitting the power to the electro-magnetic engine not exceeding 1 ohm. If, instead of going 1 mile, it was desired to go 2 miles, it would be necessary first of all to employ a conductor twice the length; but that conductor would give 2 ohms resistance, and would therefore destroy much of the effect. To bring it back to 1 ohm resistance, it would be necessary to put down a second wire, or to double the area of the first, and in that case there would be a wire of twice the length and twice the area, therefore four times the weight and four times the cost. That pointed to an increase in the cost and in the weight of the conductor in the square ratio of the distance. Having twice the area to deal with, a second generator could be put on, and electricity enough to work two machines could be sent through the double area to a double distance. The moment that was done, the conductor was increased, for the power was transmitted only in the proportion of the increase of the length; but that was not enough. The electric conductor did not resist the motion of electricity in the same manner as a pipe resisted the flow of liquid through it, but an ohm's

resistance was an ohm's resistance for a larger as well as for a smaller current flowing through it, which resistance was only increased by a rise of temperature in the conductor. This rise of temperature was kept down by dissipation of heat from the conductor; or, considering that the longer and doubled conductor would possess four times the amount of surface for the dissipation than the single and short conductor, it would be capable of transmitting four times the amount of electric current. It might, therefore, be said that it was no dearer to transmit electro-motive force to the greater than to the smaller distance, as regarded weight and cost of conductor, a result which seemed startling, but which he nevertheless ventured to put forward with considerable confidence. In uniting the two longer conductors into one, the surface would, however, be increased only in the ratio of $\sqrt{2}:1$; therefore the relative transmitting power between the longer and shorter conductor would, strictly speaking, be increased in the ratio of $1:2\sqrt{2}$, or $1:2\cdot83$, and the longer conductor would be dearer than the shorter per unit of electro-motive force transmitted in the proportion of $4:2\cdot83$.

Sir William Thomson has remarked that the question of the heat developed in the wire was the fundamental question with reference to the quantity of metal required to communicate the effect to a distance. The most practical way of producing the result would be to put the wire in the shape of a copper tube. Having a copper tube, with a moderate amount of copper in its sectional area, and a current of water flowing through it with occasional places to let it off, and places to allow water to be admitted for the purpose of cooling, there would be, without any injury to the insulation, a power of carrying off heat practically unlimited. He believed that with an exceedingly moderate amount of copper, it would be possible to carry the electric energy to a distance of several

hundred miles. The economical and engineering moral of the theory appeared to be that towns henceforth would be lighted by coals burned at the pit's mouth, where it was cheapest. The carriage expense of electricity was nothing, while that of coal was sometimes the greater part of its cost. The dross at the pit's mouth, which was formerly wasted, could be used for working dynamo-engines of the most economical kind. Nothing could exceed the practical importance of this fact. The power transmissible by these machines was not simply sufficient for working sewing-machines and turning lathes, but by putting together a sufficient number any amount of HP. might be developed. Taking the case of the machines required to develop 1000 HP., he believed it would be found comparable with the cost of a 1000 HP. engine; and he need not point out the vast economy to be obtained by the use of such a fall as that of Niagara, or the employment of waste coal at the pit's mouth.

CHAPTER VII.

EFFICIENCY OF COUPLED MACHINES.

As regards the efficiency of the system comprising two machines, the following quotation from a paper read by the Author before the Institution of Civil Engineers, 1878 (for which the Telford Medal was awarded), will fully elucidate this point:—

The means at present employed for the transmission of power to a distance are well known. In adding to the list it may be well to point out that between the use of electricity, when obtained from a voltaic battery, and conveyed to an electro-magnetic motor by conducting wires, and the employment of dynamo-machines, there is just the difference that results in obtaining the electric light by a Grove or a Bunsen battery, and in taking the light from the current produced by the dynamo-machine. In the one case an expensive chemical action is converted into force; in the other, the force produced by a steam or other economical motor is transmitted. With the electro-magnetic motor the system is generative; with the dynamo-machine, the current acts merely as a means of transmitting power produced by an independent motor. In point of fact, this independent motor may be a natural source of power, such as the fall of water, the utilisation of the product of oil wells, with prime-movers situated at these wells, etc.

The limit set by distance to the transmission of power, by means at present adopted, has been comparatively narrow. Hydraulic power has been the most adaptable, with, however, several important disadvantages. Although

electricity as a means of transmission is also limited by the distance to be traversed, the limit is in this case much more extensible, and under favourable instances practically disappears. The limit is dependent upon the quantity of electricity that can be conveyed by the conductor, since mechanical efficiency depends upon the magnetic energy.

For the transmission of power, say from a steam or water motor initially, the following system is adopted: First, a strap or belt from the motor is carried to the pulley of the driving dynamo-electric machine which generates the current. By leading wires of the required length, the electrical current generated in the first machine is conveyed to the terminals of a second and precisely similar machine. Thus the first machine generates the current which is utilised in imparting motion to the second machine. It remains to review the probable efficiency of such a system. This subject has been treated in its mathematical relations by M. Mascart in the 'Journal de Physique.'

It is well known that all magneto-electric machines, when set in motion by a current, induce in themselves, as electrical systems, currents opposing the motive current. For example, when a current from some source is directed into the coils of a dynamo-machine, the coil commences to revolve. Immediately it commences to revolve, it also begins to act as a generator, and sets up a current which is opposite in direction to the motive current, and subtractive from the strength of the latter. The current-strength from the source is, therefore, at a maximum when the second machine, or that driven by the current, is at rest. From consideration it is easily obtained that the greatest work is to be yielded by the second machine when the strength of the current given by the first machine, or source, has been reduced to one-half by the induced current from the second machine. With these machines it has been generally found that the current-

strength is proportional to the velocity or number of revolutions of the cylinder; so that, supposing two equal

FIG. 19.

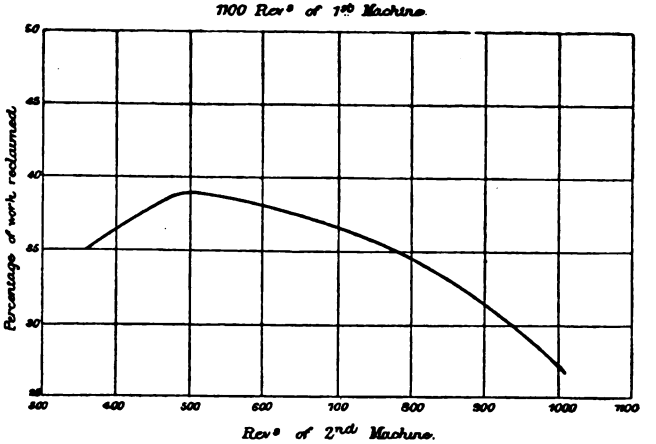
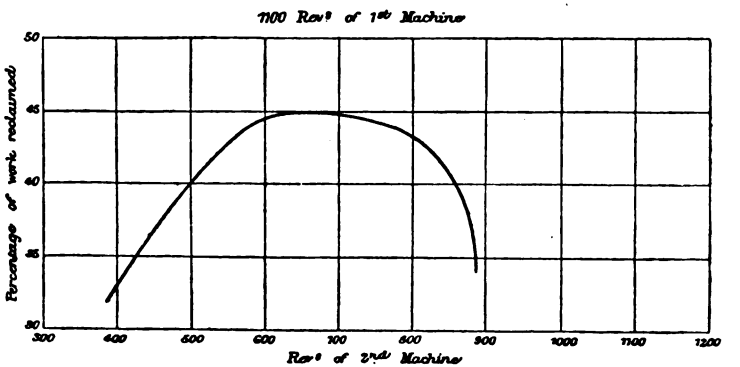


FIG. 20.

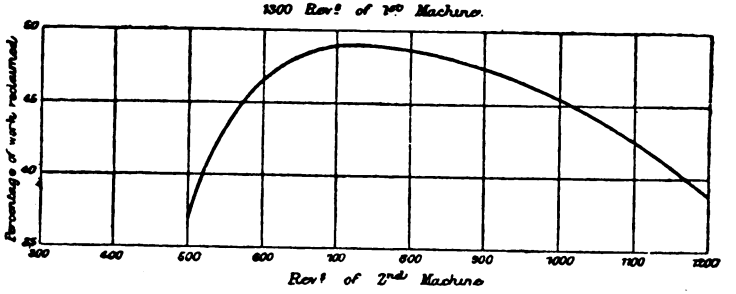


machines arranged for the transmission of power, the amount of work reclaimable from the second machine will

be 50 per cent. of that employed upon the first, and the number of revolutions of the armature of the second machine corresponding to the maximum of work reclaimed will be half the number made by the first.

Figs. 19 to 21 show curves drawn through six points from results actually obtained. The revolutions of the cylinder of the second machine are represented as abscissæ

FIG. 21.



and the work reclaimed as ordinates. The numerical values are given in the following table:—

RESULTS OF EXPERIMENTS WITH DYNAMO-MACHINES FOR THE TRANSMISSION OF POWER BY THE ELECTRIC CURRENT.

Fig. 19. Machine A, at 1100 Revolutions Driving C.		Fig. 20. Machine A, at 1100 Revolutions Driving B.		Fig. 21. Machine A, at 1400 Revolutions Driving B.	
Revolutions of C.	Per cent. of Work Reclaimed.	Revolutions of B.	Per cent. of Work Reclaimed.	Revolutions of B.	Per cent. of Work Reclaimed.
1,008	27	884	34	1,199	39
730	36	808	43	1,031	44
584	38	767	44	863	48
501	39	625	45	691	49
420	37	481	39	500	37
359	35	385	32	..	..

The departures from the theoretical values are somewhat marked, but are within the limits of error that occur with this class of measurements, made with no great attempt at accuracy.

In order to ascertain the effects of resistance in the circuit connecting the driving and driven engines, two machines were connected by leading wires, having resistance of ½ unit, 1 unit, and 1½ unit respectively. The machines were two of the smallest Siemens type, and gave without inserted resistance an efficiency of 44 per cent.; with ½ unit resistance added to the circuit the efficiency was reduced to 38 per cent., giving a loss of 6 per cent.; with 1 unit of added resistance the efficiency fell to 32 per cent., giving a loss of 12 per cent.; and with 1½ unit added resistance the efficiency was 26 per cent., giving a loss of 18 per cent. The experiments clearly proved that the loss of efficiency is proportional to the added resistance.

With a machine having 0·05 unit resistance, a current of 5 webers through one ohm has been obtained, with an expenditure of 2 HP. This gave a current of which the mechanical value, when the machine was connected to a precisely similar machine, was 56,000 foot-lbs., with the second machine at rest; and a resultant current of 29,000 foot-lbs. with the second machine in motion, the HP. expended being maintained constant. The work reclaimed, measured on the dynamometer, was 48 per cent., closely agreeing with the efficiency of one-half. As to the effect of circuit resistance on the transmission of power in the instance quoted, the addition of 1½ unit resistance reduced the efficiency to 26 per cent. with the particular machines employed; but if convolutions of wire were added to the cylinder of the machine the efficiency would again attain its maximum. It should be noted that the theoretical efficiency of 50 per cent. is referred to the use of two equal and similar machines, one used as the driving, the other as the driven machine. It is quite probable

that a larger percentage of work reclaimed might be attained by some other arrangement of machines. By driving one machine by two others coupled in series, the results of three readings gave: speed of small machines, 1060 revolutions; speed of medium machine, 1820 revolutions. The medium machine driven by one small machine gave the following results, taken from three readings: speed of small machine, 1060 revolutions; speed of medium machine, 780 revolutions. It would thus be seen that the speed of the medium machine had been rather more than doubled by driving it from two machines coupled in series. The best conditions for work admitted of direct proof. Two equal machines being employed, and a galvanometer put in circuit between them, the deflections showed that when the second machine was at rest, the current was of twice the intensity that occurred when the second machine was giving out its best work.

M. Mascart has shown that if the number of revolutions of the first machine were kept constant, the greatest efficiency would be attained when the number of the revolutions of the second machine were nearly equal to unity. But he has also proved that when the greatest amount of power was given off by the second machine, it would make half the number of revolutions of the first machine, and then the first machine would require half the power to drive it which was required when the second machine was standing, and of that power one half would be transmitted by the second machine. This is a very different thing from the conclusion that the maximum efficiency was one half.

In some experimental researches on magneto-electric machines, MM. Mascart and Angot, in the 'Journal de Physique,' vol. vii. p. 78, investigate the reaction of the magnets and the electro-magnets. Previous considerations in a former article* by these authors, give only a first ap-

* *Vide* Minutes of Proceedings Inst. C.E., vol. L., p. 302.

proximation to the action of machines containing magnets or electro-magnets. It has been supposed that the magnetism of permanent magnets is invariable, and that that of electro-magnets depends only upon the intensity of the currents by which they are surrounded; but there exist between the magnets and the currents reactions that may greatly modify the results. Electro-dynamic machines which include neither magnet nor soft iron give rise to no new correction, the time necessary for the manifestation of the electro-dynamic forces being inappreciable.

In magnetic machines of the second type the effective magnetism of the permanent magnets is changed in a complex manner by the influence of the bobbins. If it be admitted that the variation of the magnetism of the magnets is proportional to the magnetic power of the bobbins, which is in direct ratio to the intensity of the current, it is to be seen that the magnetism of the magnets will be increased when they exercise an attraction between the two systems, and that it will be diminished in the case of repulsion. The diminution of repulsive force will be greater than the increase of attractive force, since the magnets may be supposed to be in a condition bordering upon saturation; there will result from this fact a slight diminution of work, and this may be represented by a term proportional to the square of the intensity of the current. The equations * then become for the motor machine,

$$K = NH = NI(A - BI)$$

$$E = N(A - BI = N\left(A_1 - B\frac{E_0 - E}{R}\right).$$

---

* I and i are current intensities; E_0 primary electro-motive force; E contrary electro-motive force; R total resistance; N and n number of revolutions in the two machines in corresponding cases. K is the mechanical work in time dt. The other relations are explained in the text.

Whence is deduced,

$$E = N A \frac{I - \frac{E_0}{A}\frac{B}{R}}{I - N\frac{B}{R}},$$

instead of $E = N A$. The electro-motive force of induction, for a given velocity, is as much weaker as that of the battery is stronger. The machine left to itself has still a velocity, the limit of which is given by the condition $I = 0$, which is

$$N_0 = \frac{E_0}{A},$$

as if the reaction had not been taken into account. The efficiency is diminished, because it has for expression,

$$r = \frac{E}{E_0} = \frac{N A}{E_0}\frac{I - \frac{E_0}{A}\frac{B}{R}}{I - N\frac{B}{R}}.$$

To calculate the coefficients A and B the limit of velocity N_0 of the motor machine must be determined, whence is deduced

$$A = \frac{E_0}{N_0},$$

as measure for the efficiency for a given velocity; thus the equation

$$r = \frac{N}{N_0}\frac{I - N_0\frac{B}{R}}{I - N\frac{B}{R}}$$

obtains, whence is deduced

$$B = R\frac{\frac{N}{N_0} - r}{N(I - r)}.$$

The limit of velocity N_0 is easily obtained by experiment, since it is proportional to the electro-motive force of the battery employed, which may be chosen as weak as desired.

When the machine is employed as electro-motor, the condition of production $2\frac{K}{i} > R$ is always realised for a very weak current, and equilibrium exists when

$$n\left(\frac{A}{i} - B\right) = R,$$

or

$$i = \frac{A}{\frac{R}{n} + B} = \frac{nA}{R + nB} = \frac{nA}{R}\frac{1}{I + n\frac{B}{R}}.$$

The apparatus behaves as a battery, the electro-motive force of which is proportional to the velocity, with the conditions of adding to the actual resistance a fictitious resistance itself proportional to the velocity. The intensity will then have a limiting value given by the equation,

$$i \propto = \frac{A}{B}.$$

In magneto-electric machines, that is to say with fixed and moving electro-magnets, the influence of the wires of a system of bobbins on the opposed electro-magnets gives, as in the preceding, an increase of attractive forces and a greater diminution of repulsive forces, which again introduces into the work a negative variation proportional to the magnetism and to the intensity of the current that may be considered comprised in the term $C_1 M I^2$. On the other hand, the reciprocal influence of the electro-magnets gives also a diminution of work, which is sensibly proportional to the square of the magnetisation, and may be comprehended in the term $C_2 M^2 I^2$, so that there will be

nothing to modify the theory. The reaction which is weak in the machines of the second type, plays on the contrary an important part in composite machines consisting of magnets and electro-magnets. If it be considered that the magnetism of fixed magnets is modified by a quantity proportional to the magnetisation of the electro-magnets, there results a diminution of work proportional to the square of magnetisation, or to $M^2 I^2$.

The efficiency is

$$r = \frac{E}{E_0} = \frac{N(A + A_1 M)}{E_0} \cdot \frac{I - \dfrac{E_0}{A + A_1 M} \dfrac{A_2 M^2}{R}}{IN - \dfrac{A_2 M^2}{R}}.$$

If the current is sufficiently weak, so that the coefficient M has the constant value M_0, it becomes

$$r = \frac{N}{N} \frac{I - N_0 \dfrac{A_2 M_0^2}{R}}{I - N \dfrac{A_2 M_0^2}{R}},$$

an expression of the same form as for machines of the second type of magneto-electric machines. The greater number of electric motors enter into the category, because they are nearly always formed of two systems of electro-magnets—or, what is the same, of a system of fixed electro-magnets, and of movable pieces of soft iron. In these machines work has for expression,

$$K = NH = NI^2 (C + C_1 M + C_2 M^2).$$

If the intensity is feeble the parenthesis may be represented by a constant A, and

$$K = N A I^2,$$

and the electro-motive force of induction is

$$E = N A I.$$

For the other part,

$$I R = E_0 - E = R I_0 - N A I,$$

whence is deduced

$$N A = R\left(\frac{I_0}{I} - 1\right).$$

The Gramme machine with electro-magnets enters into the same type in theory, but entirely differs from the preceding in construction. This machine the Authors have studied as an electro-motor only. The resistance of the machine is not constant, because the commutator brush communicates successively with the different bobbins of the ring, but does not vary more than $\frac{1}{100}$; the mean is 1·104 ohm. The Authors have added successively exterior resistances to the amount of 200 ohms, and have varied the speed from a quarter of a revolution to nineteen revolutions per second. It should be remarked that this enormous speed can be obtained on very resistant circuits only, because the intensity increases so rapidly that with a shorter circuit all the disposable power of the motor, which equalled 5 HP., could not be utilised. All the quantities are reduced into absolute units (webers), and the resistance expressed in ohms. The phenomena are regular when the resistance does not exceed 10 ohms, nor the speed of the machine ten revolutions per second. Thus, if the quantity is inferior to 0·08 weber, it is proportional to the speed, and in inverse ratio to the total resistance of the circuit. For larger quantities the constant has for expression $\frac{i R}{n}$, which depends only upon the intensity of the current. This result accords with theory. The electro-motive force is

$$n i (C + C_1 M + C_2 M^2),$$

which gives

$$i = n\,i\left(\frac{C + C_1 M + C_2 M_2}{R}\right), \text{ or } \frac{i R}{n} = i\,(C + C_1 M + C^2 M^2).$$

The values of $\frac{i R}{n}$ increasing nearly proportionally to the quantity, calculations can be effected by the following empirical formula,

$$\frac{i R}{n} = 0{\cdot}286 + 0{\cdot}4\,i,$$

where i is the quantity of current, R the resistance of the whole circuit, and n the number of revolutions of the Gramme-armature.

CHAPTER VIII.

COMPARATIVE EFFICIENCY OF VARIOUS MACHINES.

NOTHING can be done in the inter-comparison of any natural force until accurate measurements have been made. For those measurements we are indebted to a great extent to the labours of the committee on dynamo-electric machines formed by the Franklin Institute, and to Professors Houston and Thomson's report as to the ratio of efficiency in the conversion of motive-power into electricity.

In entering this comparatively new field of research, peculiar difficulties occurred, owing to conditions that do not exist in the various forms of batteries used as sources of electrical power. In many battery circuits a high external resistance may be employed, and the electro-motive force remains comparatively constant, while in dynamo-electric machines, in which the reaction principle is employed, the introduction of a very high external resistance into the circuit must be necessarily attended by decided variations in the electro-motive force due to changes in the intensity of the magnetic field in which the currents have their origin. Moreover, a considerable difficulty is experienced in the great variations in the behaviour of these machines when the resistance of the external work is changed. Changes due to loss of conductivity by heating, also take place in the machine itself. These variations are also attended by changes in the power required to drive the machine, and in the speed of running, which again re-act on the current generated. These are certain normal conditions in the running of

dynamo-electric machines under which all measurements can be made, viz.:—

The circuit must be closed, since, on opening, all electrical manifestations cease.

The speed of the machine must be, as nearly as possible, constant.

The power required to maintain a given rate of speed must be, as nearly as possible, constant.

The machines submitted to the Committee for determination were as follows, viz.:—

1. Two machines of different size, and of somewhat different detailed construction, built according to the invention of Mr. C. F. Brush, and styled respectively in the same report as A^1, the larger of the two machines, and A^2, the smaller.

2. Two machines, known as the Wallace-Farmer machines, differing in size and in minor details of construction, and designated respectively as B^1, the larger of the two, and B^2, the smaller. In the case of the machine B^1, the experiments were discontinued after the measurement of the resistances was made, insufficient power being at disposal to maintain the machine at its proper rate of speed.

3. A Gramme machine of the ordinary construction.

All the above machines are constructed so that the whole current traverses the coils of the field magnets, being single current machines, in which the reaction principle is employed. In the case of the machine designated A^2, the commutators are so arranged as to permit the use of two separate circuits when desired.

For the purpose of preserving a ready measure of the current produced by each machine, under normal conditions, a shunt was constructed by which an inconsiderable but definite proportion of the current was caused to traverse the coils of a galvanometer, thus giving with each machine a convenient deflection, which could at any

time be reproduced. As the interposition of this shunt in the circuit did not appreciably increase its resistance, the normal conditions of running were preserved.

As indicating the preservation of normal conditions in any case, the speed of running and the resistances being the same as in any previous run, it was found that when there was an equal expenditure of power, as indicated by the dynamometer, the current produced, as indicated by the galvanometer, was in each case the same.

Certain of the machines experimented with heated considerably on a prolonged run; most of the tests, therefore, were made when the machines were as nearly as possible at about the temperature of the surrounding air.

It is evident that no other standard could be well adopted, as under a prolonged run the temperature of the different parts of the machine would increase very unequally; and, moreover, it would be impossible to make any reliable measurements of the temperatures of many such parts.

In measuring the resistance of the machines, a Wheatstone's bridge, with a sliding contact, was used in connection with a galvanometer and a suitable voltaic battery. In taking the resistances of the machines, several measurements were made with the armatures in different positions, and the mean of these measurements taken as the true resistance.

To determine the value of the current, two methods were selected, one based on the production of heat in a circuit of known resistance, and the other upon the comparison of a definite proportion of the current with that of a Daniell's battery.

In the application of the first method, eight litres of water, at a known temperature, were taken and placed in a suitable non-conducting vessel. In this was immersed a German-silver wire, and a sliding contact adjusted to

afford a resistance equal to that of the exterior resistance under consideration.

This was now introduced into the circuit of the machine. All these arrangements having been made, the temperature of the water was accurately obtained by a delicate thermometer. The current from the machine running under normal conditions was allowed to pass, for a definite time, through the calorimeter so provided. From the data thus obtained, after making the necessary corrections as to the weight of the water employed, the total heating effect in the exterior circuit, as given in Table II., was deduced.

Since the heat in various portions of an electrical circuit is directly proportional to the resistance of those portions, the total heat of the circuit was easily calculated, and is given in Table III., in English heat units.

For ease of reference, the constant has been given for conversion of these units into the now commonly accepted units of heat.

Having thus obtained the heating effect, the electrical current is—

$$C = \frac{\sqrt{W h \times 772}}{R t c},$$

where C = the weber current per ohm; W, the weight of water in pounds; h, the increase of temperature in degrees Fahr.; 772, Joule's constant; R, the resistance in ohms; t, the time in seconds; and c, the constant 0·737335, the equivalent in foot-lbs. of one weber per ohm per second. The currents so deduced for the different machines are given in Table IV.

The other method employed for measuring the current, viz. the comparison of a definite portion thereof with the current from a Daniell's battery, was as follows:—

A shunt was constructed, of which one division of the circuit was 0·12 ohm and the other 3000 ohms. In this latter division of the circuit was placed a low-resistance

galvanometer, on which convenient deflections were obtained. This shunt being placed in the circuit of the machine, the galvanometer deflections were carefully noted. These substituted resistances were immersed in water, in order to maintain an equable temperature.

Three Daniell's cells were carefully set up and put in circuit with the same galvanometer, and with a set of standard resistance coils. Resistances were unplugged sufficient to produce the same deflections as those noted with the shunt above mentioned.

The shunt ratio, as nearly as could conveniently be obtained, was $\frac{1}{25000}$. Then the formula

$$C = \frac{s\,n \times 1{\cdot}079}{R},$$

where C equals the weber current; s, the reciprocal of the shunt ratio; n, the number of cells employed; 1·079, the assumed normal value of the electro-motive force of a Daniell's cell, and R, the resistances in the circuit with the battery, gives at once the current. In comparison with the total resistances of the circuit, the internal resistance of the battery was so small as to be neglected.

The results obtained were as follows:—

Name of Machine.	Shunt Ratio.	Number of Daniell's Cells.	Resistances Unplugged	Speed of Machine.
			Ohms.	Revolutions.
Large Brush	$\frac{1}{25000}$	3	2,710	1,340
Small Brush	,,	,,	3,700	1,400
Wallace-Farmer	,,	,,	8,320	844
	,,	,,	6,980	1,040
Gramme	,,	,,	4,800	800

The weber currents, as calculated from the above data, are given in Table IV.

From the results thus derived, the electro-motive force was deduced by the general formula,

$$E = C \times R.$$

The electro-motive force thus calculated will be found in Table IV.

TABLE I.*—SHOWING WEIGHT, POWER ABSORBED, &C., BY DYNAMO-ELECTRIC MACHINES, TESTED BY A COMMITTEE OF THE FRANKLIN INSTITUTE, 1877-78.

Name of Machine.	Weight in lbs.	Copper-wire in—				Revolutions of Armature per Minute.	Foot-pounds of Power Consumed.	HP.
		Armature.		Field Magnets.				
		Size.	Weight.	Size.	Weight.			
		Inch.	lbs.	Inch.	lbs.			
Large Brush	475	0·081	32	0·134	100	1,340	107·606	3·26
Small „	390	0·063	24	0·096	80	1,400	124·248	3·76
Large Wallace . .	600	0·042	50	0·114	125	800	..	..
Small „	350	0·043	18¾	0·098	41	1,000	128·544	3·89
Gramme .	366	0·059	104	0·108	104	800	60·992	1·84

Statements are frequently made, when speaking of certain dynamo-electric machines, that they are equal to a given number of Daniell's or other well-known battery cells. It is evident, however, that no such comparison can properly be made, since the electro-motive force of a dynamo-electric machine, in which the reaction principle is employed, changes considerably with any change in the relative resistances of the circuit of which it forms a part, while that of any good form of battery, disregarding polarisation, remains approximately constant. The internal

* These reports have been condensed to show merely the power expended and returnable by dynamo-electric machines.

resistance of dynamo-electric machines is, as a rule, very much lower than that of any ordinary series of battery cells, as generally constructed, and therefore, to obtain with a battery conditions equivalent to those in a dynamo-electric machine, a sufficient number of cells in series would have to be employed to give the same electro-motive force; while, at the same time, the size of the cells, or their number in multiple arc, would require to be such that the internal resistance should equal that of the machine.

Suppose, for example, that it be desired to replace the large Brush machine by a battery whose electro-motive force and internal and external resistances are all equal to that of the machine, and that we adopt as a standard a Daniell's cell, of an internal resistance of, say, one ohm. Referring to Table IV., the electro-motive force of this machine is about 39 volts, to produce which about 37 cells, in series, would be required; but, by Table II., the internal resistance of this machine is about 0·49 ohm. To reduce the resistance of our standard cells to this figure, when 37 cells are employed in series, 76 cells in multiple arc would be required. Therefore, the total number of cells necessary to replace this machine would equal 37×76, or 2812 cells, working over the same external resistance. It must be borne in mind, however, that although the machine is equal to 2812 of the cells taken, that no other arrangement of these cells than that mentioned, viz. 76 in multiple arc and 37 in series, could reproduce the same conditions, and, moreover, the external resistances must be the same. The same principles applied to other machines would, when the internal resistance was great, require a large number of cells, but arranged in such a way as to be extremely wasteful, from by far the greater portion of the work being done in overcoming the resistance of the battery itself.

The true comparative measure of the efficiency of dynamo-electric machines as means for converting motive-

power into work derived from electrical currents, is found by comparing the units of work consumed with the equivalent unit of work appearing in the circuit external to the machine. In Table V. the comparative data are given.

The heat due to local circuits in the conducting masses of metal in the machines, irrespective of the wire, consumes force in what may be conveniently described as the *local action* of the machine, and is manifestly comparable to the well-known local action of the voltaic battery, since in each case it not only acts to diminish the effective current produced but also adds to the cost.

No determinations made with an unknown or abnormal external resistance can be of any value, since the proportion of work done, in the several portions of an electrical circuit, depends upon and varies with the resistances they offer to its passage. If, therefore, in separate determinations with any particular machine, the resistance of that part of a circuit the work of which is measured, be in one instance large in proportion to the remainder of the circuit, and in another small, the two measurements thus made would give widely different results, since in the case where a large resistance was interposed in this part of the circuit, the percentage of the total work appearing there would be greater than if the small resistance had been used. Wherever an attempt has been made to determine the efficiency of a single machine, or of the relative efficiency of a number of machines, by noting the quantity of gas evolved in a voltameter, or by the electrolysis of copper sulphate in a decomposing cell, when the resistance of the voltameter or decomposing cell did not represent the normal working resistance, it is manifest that the results cannot properly be taken as a measure of the actual efficiency.

During any continued run, the heating of the wire of the machine, either directly by the current, or indirectly from conduction from those parts of the machine heated

by local action, as explained in a former part of this report, produces an increased resistance, and a consequent falling off in the effective current. Thus, in Table II., at the temperature of 73·5° Fahr., A^1, the large Brush machine, had a resistance of 0·485 ohms, while at 88° Fahr., at the armature coils, it was 0·495 ohm. These differences were still more marked in the case of B^1.

In A^2, the small Brush machine, it will be noticed that two separate values are given for the resistance of the machine. These correspond to different connections, viz. the resistance, 1·239 ohms, being the connection at the commutator for low resistance, the double conducting wires being coupled in multiple arc, while 5·044 ohms represent the resistance when the sections of the double conductor are coupled at the commutator in series.

Referring to Table III., the numbers given in the column headed "Heat in external circuit" are the measure of the total heating power in that portion of the circuit external to the machine.

In the column headed "Total heat of circuit" are given the quantities of heat developed in the whole circuit, which numbers, compared with those in the preceding column, furnish us with the relative proportions of the work of the circuit, which appear in the external circuit.

The column headed "Heat per ohm per second" gives the relative work per ohm of resistance in each case, and these numbers, multiplied by the total resistance, give the total energy of the current expressed in heat units per second.

In Table IV. are given the results of calculation and measurement as to the electrical work of each machine.

It is evident to those acquainted with the principles of electrical science, that in the weber current and the unit electro-motive force, we have the data for comparing the work of these machines with that of any other machine or

TABLE II.—RESISTANCE OF DYNAMO-ELECTRIC MACHINES. DEDUCED FROM DETERMINATIONS BY PROFESSORS HOUSTON AND THOMSON.

Name of Machine.	Temperature in degrees Fahr.	Resistances.		Resistance of Conducting Wire.	Total Resistance of the Circuit.	Remarks.
		Of Machine + Conductor.	External.			
					Ohms.	
A^1, large Brush .	73½	0·485	0·57	0·016	1·055	At beginning of run.
A^1 „ „ .	88	0·495	0·82	0·016	1·315	After running 25 minutes.
A^2, small „ .	74	1·255	1·70	0·016	2·955	Arranged for low resistance.
A^2 „ „ .	74	5·06	..	0·016	..	„ „ high „
B^1, large Wallace .	74	4·60	1·98	0·016	6·58	Machine cold.
B^1 „ „ .	118	5·13	..	..	..	After 40 minutes' run.
B^2, small „ .	74	4·96	2·87	0·016	7·83	At 844 revolutions.
B^2 „ „ .	74	4·96	3·87	0·016	8·24	„ 1000 „
Gramme	68	1·685	1·35	0·016	3·04	Arc not normal.
„	68	1·685	1·97	0·016	3·66	Arc normal.

TABLE III.—THERMIC EFFECTS OF DYNAMO-ELECTRIC MACHINES. DEDUCED FROM DETERMINATIONS BY PROFESSORS HOUSTON AND THOMSON.

Name of Machine.	Galvanometer with Shunt.	Heating Effect in External Circuit.			Resistance of Calorimeter Equal to External Circuit.	Heat in External Circuit in Pounds H_2O, 1° Fahr.	Total Heat of the Circuit in Pounds, H_2O, 1° Fahr.	Heat per ohm per second.	Speed of Machine, Revolutions per minute.	Dynamometer Reading, Including Friction.
		Pounds H_2O.	Increase, Degrees Fahr.	Duration of Run.						
A^1, large Brush .	51½°	18·64	23·25	10	0·82	43·338	69·49	0·881	1,340	107,606
A^2, small „ . .	34	18·63	9·09	5	1·70	33·87	58·87	0·332	1,200	117,700
A^2 „ „ . .	37	18·63	18·66	8	1·70	43·45	75·57	0·426	1,400	124,248
B^2, small Wallace .	25½	18·63	11·50	12	2·87	17·85	48·70	0·104	844	97,068
B^2 „ „ .	55½	18·63	4·92	6	2·87	15·28	41·69	0·089	844	97,068
B^3 „ „ .	24½	18·64	10·75	10	3·28	20·04	50·34	0·102	1,040	128,544
Gramme	38	18·64	16·25	10	1·97	30·29	56·28	0·256	800	60,992

For conversion to metrical heat units, 1 lb. water 1° Fahr. = 259·185 grammes of water, 1° centigrade.

TABLE IV.—CURRENT AND ELECTRO-MOTIVE FORCE OF DYNAMO-ELECTRIC MACHINES. DEDUCED FROM DETERMINATIONS BY PROFESSORS HOUSTON AND THOMSON.

Name of Machine.	Weber Current per Ohm per Second.		Electro-motive Force, in Volts.		Per cent. of the Work of Current appearing in the External Circuit.	Corresponding Dynometric Values.	Remarks.
	From Heat Developed.	By Comparison with Daniell's cell. Volt.	Calculated from Heat as Resistance.	By Comparison with Daniell's cell. Volt.			
A^1, large Brush .	30·37	29·87	39·94	39·28	60·08	107,606	Speed 1,340 revolutions.
A^2, small „ . .	18·63	..	55·05	..	..	117,700	„ 1,200 „
A^2 „ „ . .	21·12	21·87	62·41	64·63	56·51	124,248	„ 1,400 „
B^2, small Wallace .	10·42	9·73	81·59	76·19	35·38	97,068	„ 844 „
B^2 „ „ .	9·63	..	75·48	..	..	..	„ 844 „
B^2 „ „ „	10·33	11·16	85·12	91·96	38·59	128,544	„ 1,040 „
Gramme	16·38	16·86	59·95	61·71	51·09	60,992	„ 800 „

battery, whether used for light, heat, or electrolysis, or any other form of electrical work.

The values of the weber current, as deduced from the heat developed, and from the comparison with a Daniell's cell, do not exactly agree; nor could this have been expected, when the difficulty of minutely reproducing the conditions as to speed, resistance, etc., is considered.

By comparison of the electro-motive force of the different machines, it appears that no definite unit seems to have been aimed at by all the makers.

Table V. is designed especially to permit a legitimate comparison of the relative efficiency in converting motive-power into current. The actual dynamometer reading is given in the first column. On account of the differences of construction and differences in speed of running, the friction and resistance of the air vary greatly, being least with the Gramme, as might be expected, since the form of the revolving armature and the speed of the machine conduce to this result. This is, of course, a point greatly in favour of the Gramme machine.

That portion of the power expended available for producing current is given in the third column, being the remainder, after deducting the friction, as above mentioned; but this power is not in any case fully utilised in the normal circuit. This is found to be the case by comparing calculations of the total work of the circuit in foot-lbs. expended in producing such current as given in the appropriate column.

For instance, in the case of A^1, the large Brush machine, the available force for producing current is 89,656 foot-lbs. per minute, of which only 53,646 reappear as heat in the circuit. The balance is most probably expended in the production of local currents in the various conducting masses of metal composing the machine. The amount thus expended in local action is given in the column designated "F. P., unaccounted for in the circuit." A

TABLE V.—EFFECTS OF DYNAMO-ELECTRIC MACHINES IN FOOT-POUNDS PER MINUTE. DEDUCED FROM DETERMINATIONS BY PROFESSORS HOUSTON AND THOMSON.

Name of Machine.	Dynamometer reading. Foot-pounds Consumed.	Friction and Resistance of Air.	Foot-pounds Consumed after Deducting Friction.	Foot-pounds Appearing in the External Circuit.	Foot-pounds Appearing in whole Circuit.	Foot-pounds Unaccounted for in the Circuit.	Per cent. of Power Utilised in the External Circuit.	Per Cent. of Effect after Deducting Friction.
A^1, large Brush .	107,606	17,950	89,656	33,457	53,646	36,010	31	37½
A^2, small „ . .	117,700	12,328	105,372	26,148	45,448	59,924	22	25
A^2 „ „ . .	124,248	14,976	109,272	33,543	58,340	50,932	27	31
B^2, small Wallace .	96,068	7,800	89,268	13,780	37,596	51,672	14	15½
B^2 „ „ .	128,544	11,072	117,472	15,469	38,862	78,610	12	13
Gramme . . .	60,992	4,512	56,480	23,384	43,448	13,032	38	41

For conversion into Gramme-mètres — 1 foot-pound = 138 Gramme-mètres, nearly.

comparison of the figures in this column is decidedly in favour of the Gramme machine, it requiring the smallest proportion of power expended to be lost in local action. When, however, we consider that the current produced by the large Brush machine is nearly double that produced by the Gramme, the disproportion in the local action is not so great.

The determinations made enabled the following opinions to be formed as to the comparative merits of the machines submitted for examination:—

The Gramme machine is the most economical, considered as a means for converting motive-power into electrical current, giving a useful result equal to 38 per cent., or to 41 per cent., after deducting friction and the resistance of the air. In this machine the loss of power in friction and local action is the least, the speed being comparatively low.

The large Brush machine comes next in order of efficiency, giving useful effect equal to 31 per cent. of the total power used, or 37½ per cent. after deducting friction. This machine is, indeed, but little inferior in this respect to the Gramme, having, however, the disadvantage of high speed, and a greater proportionate loss of power in friction, etc. This loss is nearly compensated by the advantage this machine possesses over the others of working with a high external, compared with the internal, resistance, this also insuring comparative absence of heating in the machine. This machine gave the most powerful current.

The small Brush machine stands third in efficiency, giving a useful result equal to 27 per cent., or 31 per cent. after deducting friction. Although somewhat inferior to the Gramme, it is, nevertheless, a machine admirably adapted to the production of intense currents, and has the advantage of being made to furnish currents of widely varying electro-motive force. By suitably

connecting the machine, as before described, the electromotive force may be increased to over 120 volts. It possesses, moreover, the advantage of division of the conductor into two circuits, a feature which, however, is also possessed by some forms of other machines. The simplicity and ease of repair of the commutator are also advantages. Again, this machine does not heat greatly.

The Wallace-Farmer machine does not return to the effective circuit as large a proportion of power as the other machines, although it uses, in electrical work, a large amount of power in a small space. The cause of its small economy is the expenditure of a large proportion of the power in the production of local action. By remedying this defect a very admirable machine would be produced. After careful consideration of all the facts, the Committee unanimously concluded that the small Brush machine, though somewhat less economical than the Gramme machine, or the large Brush machine, was, of the machines experimented with, the best adapted for the various purposes of the Institute, chiefly for the following reasons: It is adapted to the production of currents of widely-varying electro-motive force, and from the mechanical details of its construction, especially at the commutators, it possesses great ease of repair to the parts subject to wear.

During the competitive trials at the Franklin Institute, as to the relative efficiency of the machines, as noted in the preceding pages, Professors Houston and Thomson took the opportunity thus afforded to make a careful study of many interesting circumstances which influence the efficiency of these machines.

A convenient arrangement of the particular circumstances to be discussed is: (1) those affecting the internal work of the machines; (2) those affecting the external work; and (3) the relations between the internal and external work.

The mechanical energy employed to give motion to a dynamo-electric machine is expended in two ways: (1) in overcoming the friction and the resistance of the air; and (2) in moving the armature of the machine through the magnetic field, the latter, of course, constituting solely the energy available for producing electrical currents. The greatest amount of power expended in the first way was noticed to be about 17 per cent. of the total power employed. This expenditure was clearly traceable to the high speed required by the machine. The speed, therefore, required to properly operate a machine is an important factor in ascertaining its efficiency. The above percentage of loss may not appear great; but when it is compared with the total work done in the external circuit, constituting as it did in this particular instance over 50 per cent. of the latter, and about 33 per cent. of the total work of the circuit, its influence is not to be disregarded. In another instance the work consumed as friction was equal to about 80 per cent. of that appearing in the external circuit as heat, while in the Gramme machine experimented with this percentage fell to 20, and was only about 7 per cent. of the total power consumed in driving the machine.

In regard to the second way in which mechanical energy is consumed, in overcoming the resistance necessary to move the armature through the magnetic field, or, in other words, to produce electrical currents, it must not be supposed that all this electrical work appears in the circuit of the machine, since a considerable portion is expended in producing local circuits in the conducting masses of metal, other than the wire, composing the machine.

The following instances of the relation between the actual work of the circuit, and that expended in local action, will show that this latter is in no wise to be neglected. In one instance an amount of power, some-

what more than double the total work of the circuit, was thus expended. In another instance it constituted less than one-third the total work of the circuit.

Of course, work expended in local action is simply thrown away, since it adds only to the heating of the machine. And, since the latter increases its electrical resistance, it is doubly injurious.

The local action of dynamo-electric machines is analogous to the local action of a battery, and is equally injurious in its effect upon the available current.

Again, in regard to the internal work of a machine, since all this is eventually reduced to heat in the machine, the temperature during running must continually rise until the loss by radiation and convection into the surrounding air equals the production, and thus the machine will acquire a constant temperature. This temperature, however, will differ in different machines, according to their construction, and to the power expended in producing the internal work, being, of course, higher when the power expended in producing the internal work is proportionally high.

If, therefore, a machine during running acquires a high temperature when a proper external resistance is employed, its efficiency will be low. But it should not be supposed that because a machine, when run without external resistance—that is, on short circuit—heats rapidly, that inefficiency is shown thereby. On the contrary, should a machine remain comparatively cool when a proper external resistance is employed, and heat greatly when put on short circuit, these conditions should be regarded as a proof of its efficiency.

In regard to the second division, the external work of the machine, this may be applied in the production of light, heat, electrolysis, magnetism, &c.

Perhaps the highest estimate that can be given of the efficiency of dynamo-electric machines, as ordinarily used,

is not over 50 per cent.; measurements have not given more than 38 per cent. Future improvements may increase this proportion. Since the efficiency of an ordinary steam-engine and boiler in utilising the heat of the fuel is probably over-estimated at 20 per cent., the apparent maximum percentage of heat that could be recovered from the current developed in a dynamo-electric machine would be over-estimated at 10 per cent. The economical heating of buildings by means of electricity may, therefore, be regarded as totally impracticable.

In respect to the relations that should exist between the external and the internal work of dynamo-electric machines, it will be found that the greatest efficiency will, of course, exist where the external work is much greater than the internal work, and this will be proportionally greater as the external resistance is greater.

CHAPTER IX.

OTHER THEORETICAL CONSIDERATIONS.

MR. DESMOND FITZGERALD has pointed out that in the case of any electro-motor the equation $I = \frac{E}{R}$ is strictly applicable.

In the voltaic battery, however, a variation of R does not necessarily affect E which is altogether independent of such variation when this occurs in the external portion of the circuit. Thus we have generally $I \propto \frac{1}{R}$, or current varies inversely as the resistance in circuit.

Again, a variation of E does not necessarily affect R; and, when the external resistance of the circuit bears a high ratio to the battery resistance, a variation of the electro-motive force, from E to E_1—and addition to, or diminution of, the number of cells in series—causes the current to vary approximately in the ratio $\frac{E_1}{E}$. Accurately, the variation in any case is determined by the ratio $\frac{E_1 R}{E R + E_1 \rho}$, when ρ is the resistance of the cell or cells added or subtracted. Thus,

$$\frac{E_1}{E} \times \frac{E_1 R}{E R + E \rho} = \frac{E_1}{R + \rho}.$$

Thus, in the case of a telegraph circuit, for instance, we have, approximately, $I \propto E$. On the other hand, in the

dynamo-electric machine, converting into electrical work a given HP., $I \propto \frac{1}{\sqrt{R}}$, since the ratio $\frac{E^2}{R}$ being constant, $E^2 \propto R$, $E \propto \sqrt{R}$, and $\frac{E}{R} \propto \frac{\sqrt{R}}{R} = \frac{1}{\sqrt{R}}$. Thus, any variation of R in this case necessarily affects E.

Again, any variation of E necessarily affects R; and the product E I being constant, we have $I \propto \frac{1}{E}$, a somewhat startling result, which to some observers has appeared contradictory to the law of Ohm. With this, however, it is in perfect accord—in effect, since $E \propto \sqrt{R}$, $R \propto E^2$, and $\frac{E}{R} \propto \frac{E}{E^2} = \frac{1}{E}$; or, when E is varied, the current varies inversely as the electro-motive force, because the resistance varies as the square of this value.

It will be seen that $R \propto E^2 = \frac{1}{I^2}$, and that the same quantity of work will be done by the current whatever may be the resistance in circuit.

If hp. be taken to express the total horse-power converted into electrical work (in the whole circuit), under the best conditions, with a Gramme machine of the form experimented with at the Franklin Institute,

$$HP. = hp. \times 1{\cdot}39,$$

and the efficiency of the machine is expressed by

$$\frac{hp.}{HP.} = 0{\cdot}72 \text{ (nearly)}.$$

Or the machine can convert into electrical work 72 per cent. of the energy expended upon it.

The ratio $\frac{hp.}{HP.}$ is the measure of the efficiency of dynamo-

electric machines. In the case of the Gramme machine under the best conditions, we have

$$HP. = hp. \times 1{\cdot}39.$$

Mr. L. Schwendler has observed that the currents produced by dynamo-electric machines, as the insertion of a Bell telephone (used as a shunt) will easily prove, are not steady. The dynamo-electric machine with the greatest number of sections in the induction cylinder gives the steadiest current. Twelve sections are found to be necessary and sufficient. That the current produced by any dynamo-electric machine through a given constant total resistance in circuit increases permanently with the speed of the induction cylinder. This increase of current for low speeds is more than proportional to the speed; afterwards it becomes proportional, and for high speeds the increase of current is less than proportional to the speed. The current has, however, no maximum for any speed, but reaches its greatest value at an infinite speed. This same law, as the total resistance in circuit is supposed to be constant, of course holds good also for the electro-motive force of the dynamo-electric machine.

Keeping the speed constant, the electro-motive force of any dynamo-electric machine decreases rapidly with increase of external resistance. This decrease is more rapid the smaller the internal resistance of the dynamo-electric machine is made. Hence the currents must decrease much more rapidly than proportional to the total resistance in circuit. As in the case of speed, the electro-motive force has no maximum for a certain external resistance, but approaches permanently its greatest value for an external resistance equal nil. It appears that the function which connects electro-motive force and speed is the same as that which connects electro-motive force and external resistance. We have only to substitute for speed the

inverse of resistance, and vice versâ. As to the maximum work by a current in a resistance r, the current decreased much more rapidly than the total resistance in circuit increased, and this resistance r should invariably be made smaller than the remaining resistance of the circuit, i.e., smaller than the internal resistance of dynamo-electric machines plus resistance of leading wires.

With regard to the electro-motive force of a dynamo-electric machine as a function of the resistance and speed, it appears that the formulæ are most probably correct for all dynamo-electric machines if the loss of current by transmission is taken into account:

$$\mathrm{E} = \kappa \left\{ 1 - \frac{1}{e^{\left(\frac{a}{m+r}\right)^2}} \right\},$$

E being the E M F, m the internal resistance, and r the external resistance, including resistance of leading wire. k and a are independent of m and r, and are the functions of the speed of the induction cylinder, containing also the construction coefficients. e is the basis of the natural logarithm. Further,

$$\mathrm{E}^1 = \kappa^1 \left\{ 1 \frac{1}{e^{\left(\frac{v}{a^1}\right)^2}} \right\},$$

E^1 being the E M F, and v the speed of the induction cylinder. k^1 and a^1 are independent of v and are functions of m and r only. These two functions, E and E^1, correspond to all the characteristics of the curves found by experiment, and they also fulfil the limit conditions.

In respect to the regularity of the production of currents by dynamo-electric machines at different periods, if the brushes are well set, and if they are placed as nearly as

possible in the neutral line of the commutator,* the production of current is perfectly regular, and measurements taken through the same external resistance at the most distant periods agree most perfectly with each other, supposing the correction for variation in speed and internal resistance to be applied. Disregarding the heating of the dynamo-electric machine by the current, the time required to arrive at dynamic equlibrium, i.e., when force transmitted, current, and magnetism received are constant, is very short indeed, especially for strong currents.

As the power which is represented by the measured current working through a given resistance can never exceed the original power transmitted to the machine, we can, from current, resistance, and force measurements, frame a formula which checks the probability of the results. This formula is:

$$C \leqq 0{\cdot}33 \sqrt{\frac{W^1 - w^1}{r + m}}.$$

W^1 is the total power consumed by any dynamo-electric machine when producing the observed current C in a circuit of resistance $r + m$; w^1 is the power consumed by the dynamo-electric machine when producing no current (i.e. driven empty, circuit open, external resistance infinite); r is the external resistance, and m the internal resistance. In the above formula C is in webers, W^1 and w^1 in meg-ergs per second, and r and m in Siemens' units. Of late, exaggerated statements of the performance of dynamo-electric machines have been made, the absurdity of which would have become evident at once if the above formula had been applied as a check to the results.

If all the work $(W^1 - w^1)$ were transformed into available

* M. A. Breguet states that the maximum and steadiest current results from the brushes being placed at an angle with the neutral line, dependent in amount upon v.

current in the external circuit, then $\frac{W^1 - w}{W}$ = unity, where W is the total work performed by the observed current in a circuit of known resistance. In practice it will be found, however, that $\frac{W^1 - w^1}{w} > 1$ (for many reasons). This expression, $\frac{W^1 - w^1}{W}$, is called the coefficient of transmission, and designated by the letter k. k is different for the different dynamo-electric machines which have been tried, and decreases with increase of current. Producing currents above 24 webers, the following average values of k have been obtained:—

κ.	Average Current in Webers.
1·01	31·0
1·12	31·1
1·28	27·9

$\frac{w}{W^1 - w^1}$; w is the useful work done in the circuit by the current. As the resistance of dynamo-electric machines and leading wires cannot be made nil, the coefficient of efficiency must be always smaller than unity. For currents above 24 webers, we have:—

e.	Average Current.
0·62	29·5
0·53	31·0
0·47	32·6
0·30	27·9

As to the practical mechanical equivalent of the currents produced by dynamo-electric machines, it $= \frac{W^1 - w^1}{C}$, where C is the current in webers. Above 24 webers, different dynamo-electric machines produce the weber at the following comsumption of power: 1 weber at 686·5 meg-ergs per second, 1 weber at 736 meg-ergs per second, 1 weber at 920 meg-ergs per second.

CHAPTER X.

CONCLUSIONS.

THE feasibility of electric transmission of power having been proved from consideration of mechanical efficiency both as regards current developed from mechanical power and as mechanical power reclaimed from the current thus produced, we have learnt from unimpeachable evidence that the power reclaimed may easily amount to 48 per cent. of that expended in the first instance. This amount of reclaimed power is indubitably superior to that obtained with compressed air, and approaches the practical efficiency of hydraulic transmission. Electric transmission has, however, the unparalleled advantage of being superior to the obstacle presented by distance, whilst it is at the same time easily portable, and can be changed in direction, as well as in intensity, at will. No force appears in the connecting portions or conductor, such as appears during mechanical transmission with shafting, or in pipes with compressed air or water. The conductor appears inert, and can be shifted, bent, or in any way moved whilst transmitting many horse-power. Its continuity must not, of course, be interrupted.

The source of power and the point of reclamation may be relatively situated most awkwardly, but the electric conductor can be brought round the sharpest corner, or carried through the most private room without inconvenience. There is nothing to burst or give way. The same circuit as may be tapped to provide the means of working power-machinery can be as conveniently tapped to work a sewing-machine.

In mining operations electric transmission will doubtless become of the highest value, since it involves no danger. Machines for this purpose could be easily constructed without a commutator, so that sparks could be avoided, with only small loss of power. The ready portability offers great inducements to the mining engineer. For ploughing by power, trials made in France show that electricity can replace steam with advantage and economy. And, in Scotland, power obtained from a waterfall has been transmitted one mile and a half.

Dredges could be reduced in size, and worked from a central motor, so that smaller channels could be cleansed mechanically than are now subject to this method. In mills and factories inaccessible rooms can be utilised for power-worked machinery. These are but a few advantages. A millennium might be anticipated when the water-power of a country shall be available at every door, for electric-power conductors can be laid in the streets more easily than gas or water-pipes.

But, says the economist, what about cost? Acknowledging these great advantages, what is there to pay for them? And the economist can be satisfactorily answered. Leaving out of count the scheme proposed by Sir William Thomson, in which we might have our water conveyed to us through pipes, the metal of which conducted the electricity for our power, we have to consider what is necessary in transmitting power electrically.

First, we require to generate our electricity, and water-power is, of course, preferable if available. If not available to generate electricity, it surely will not be available to compress air or force water, because these are only to be carried through comparatively short distances, and the original power question may be cancelled from the equation as being a common element. Reference, it need scarcely be said, is made only to cases where distance is involved. As our efficiency is good, we have only to consider (1) the

cost of the motor and moved engines, and (2) the cost of the conducting systems.

The motor and moved engines being in practice identical, the consideration of one suffices for both. These machines, as has been shown, are very simple in construction, and consist essentially of so much cast-iron and insulated copper wire, the market prices of which are known, so that the cost of any machine for developing so much horse-power may be easily calculated. The labour of construction *should* form an unimportant item, for none of the skill is involved such as is required in the construction of even the most common steam, air, or gas-engine. The quantities of materials required are but little, if more, costly, in the case of electric machines, and this excess of cost is due to infrequency of demand. The construction of machines of size hitherto unattempted is not required, and it has been shown by Prof. Thomson that electric machines of 1000 HP., as proposed by Dr. Siemens, are not necessary, so that there would be no need to attempt to refute the question of cost of so unusually large-sized engine as of that Mr. Sprague has entered into. It has been shown that ten 100-HP. engines would give better results as regards efficiency, whilst at the same time it would be nearly impossible that all the machines could fall out of repair simultaneously.

The arrangements of machines being thus consonant with the use of a small conductor, as shown in the previous pages, there is the further advantage in laying this conductor, that no air or water-tight joints have to be made. Taking such joints into consideration, it would be easy to show by figures that an efficiently insulated electric conductor to *transmit the same power* could be laid at *less* cost than with air or water, and certainly less than with gas pipes.

The advantages of electric transmission, it is to be hoped, are worthy therefore of the attention of every engineer interested in transmitting power.

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